PRESIDENTIAL INITIATIVE

ENHANCING WATER QUALITY

USDA

GROUND WATER QUALITY

INITIATIVE

ARS BIOLOGICAL CONTROL

ACTION PLAN

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EXECUTIVE SUMMARY

Over 97% of the rural residents in the U.S. obtain their drinking water from underground sources and 40% (nearly 74 million people) of the population served by public water suppliers use ground water. There is, understandably, a major concern for the potential contamination of this supply with poisonous chemical pesticides. The total withdrawal of these pesticides without development of alternatives would have a devastating effect on our economy through the drastic decrease in crop and fiber yields, and cattle production. The ARS has developed, as part of the PRESIDENTIAL INITIATIVE TO ENHANCE WATER QUALITY, a research action plan to develop biological control alternatives to chemical pesticides. This technology, used in concert with other management practices, will reduce the threat of ground water contamination by chemical pesticides. The major thrusts in biological control are:

Nematicide Reduction - Bacteria and Fungi Biocontrol Agents

- o Nematode control on Corn
- o Nematode control on Soybeans
- o Nematode control on Potatoes

Fungicide Reduction - Bacteria, Fungi, and Actinomycetes Biocontrol Agents

- o Soil borne diseases on Potatoes
- o Soil borne diseases of Vegetables
- o Seedling diseases of Cotton

Herbicide Reduction - Importation of Natural Enemies, Microbial Herbicides

- o Cocklebur, Velvetleaf, Field Bindweed, in Corn and Soybeans
- o Cocklebur, Field Bindweed and Johnson Grass in Cotton

Insecticide Reduction - Importation of Natural Enemies, Microbial Insecticides

- o Corn Rootworm and European Corn Borer on Corn
- o Colorado Potato Beetle and Green Peach Aphid on Potatoes
- o Mexican Bean Beetle on Soybeans

The development of the ARS Biological Control Action Plan is a Dynamic process. It is anticipated that this document will be updated on an annual basis to reflect acquisition of new information and thus changing priorities. The implementation of this program will depend upon both redirection of existing programs and development of additional resources.

INTRODUCTION

Reduction of Pesticide Contaminants in Ground Water by Implementing Biological Methods to Control Pests

PROBLEM DESCRIPTION AND IMPORTANCE

Over 97% of the rural residents in the U.S. obtain their drinking water from underground sources and 40% (nearly 74 million people) of the population served by public water suppliers use ground water. Ground water usage is increasing (Nielsen and Lee 1987).

Insecticide use constituted the largest proportion of pesticide use in the 1960s, but herbicides accounted for 2/3 of all pesticides used by 1975 (M. K. Hinkle, pers. comm.). Projected agricultural pesticide use in 1989 is expected to increase by 7% over that in 1988. Pesticide use on major field crops is projected at 470 million pounds active ingredients in 1989. Herbicides will account for 86% of the total use while insecticides make up 13% (USDA, Economic Research Service, 1989). The major use of herbicides will be in corn and soybean; insecticides will be mostly applied to corn, cotton, and soybeans. Over 85% of fungicide use will be in peanuts. Atrazine, alachlor, and metolachlor are widely used in corn for weed control. Insecticides most widely used in corn (35% total acreage treated) include terbufos (31%) and chlorpyrifos (30%).

In 1979, dibromochlorpropane (DBCP) and aldicarb were found in ground water in California and New York, respectively. Later, DBCP was found in ground water in four additional states and aldicarb was found in Wisconsin in 1980. Ethylene dibromide (EDB) was discovered in wells in 1982 in California and Georgia; by 1983 it was also detected in Florida and Hawaii. Consequently, EDB soil use was suspended by the EPA in 1983. By 1986, 19 different pesticides were detected in 24 states, and the source of these contaminants was believed to be from agricultural applications (nonpoint source) (U.S. Environmental Protection Agency, 1987).

Williams et al. (1988) reported 46 pesticides detected in ground water in 26 states. These pesticide contaminants were confirmed as having resulted from agricultural practices. Major corn/soybean producing states, particularly Iowa, Wisconsin, and Nebraska, rank among the higher citations with 7, 7, and 8 different pesticides each, respectively. On the other hand, northeastern states had even more pesticides detected in ground water, e.g., Maine (10), New York (11) and Connecticut (8). Midsouth states were generally low in detections, except for Mississippi with 12 different pesticide contaminant detections attributable to agricultural usage.

The pesticides most often found in ground water among the states were the herbicides alachlor (12), atrazine (13), cyanazine (6), metolachlor (5), metribuzin (5), and simazine (7). Insecticides found included aldicarb (7), carbofuran (3), fonofos (2), and oxamyl (3). Generally, these insecticides, except for oxamyl, are also applied to the soil at high rates for nematode control. Fungicides are used in relatively low quantities but have been labeled as

possible risks as tumor causing (Captan), birth defect causing, and as carcinogens (EBDC).

The significance of the ground water presence of pesticides and their metabolites to human health is unknown. Typically, these chemicals are detected at very low concentrations though they have been found at concentrations equal to or exceeding that of Health Advisory levels. Nevertheless, chemical degradation may occur slowly and contamination can persist for years, e.g., the organochlorines.

The public perception is that farm chemicals in ground water are a health threat and limiting farm chemical usage is warranted (Pins 1986). Consequently, the USDA has proposed "a major Federal and State collaborative plan to determine the magnitude and scope of the ground water quality problem and to develop resource management strategies for minimizing any contribution from agriculture to the problem" (USDA 1989).

GOALS AND OBJECTIVES

A goal of the USDA plan is "to develop new and improved agricultural systems that are cost effective and enhance ground water quality" (Goal 2). Of the six objectives in this plan, two pertain to Goal 2. These are:

> * Develop new and modified crop and livestock production systems that substantially decrease the movement of potentially hazardous chemicals into ground water, and determine the effects of these new systems on farm costs, changes in farm inputs and production choices.
>
> * Develop decision-aid systems that may be used by technical and farm management specialist, Extension agents, and farm consultants to help individual farmers select, apply, and manage profitable and environmentally sound crop and livestock production practices.

The Biological Control Component to the USDA Ground Water Quality Initiative was formulated at the request of C. R. Amerman, Special Assistant to the Administrator, and at the initiative of R. S. Soper (Soper/King, 4 April 1989). Specific guidance to the Biological Control Component was given in the Soper/King memo as follows: "The biological control plan should be targeted against those pests that are currently being controlled by chemical pesticides which in turn are contaminating groundwater. Thus the biological control plan should exclude pests whose chemical control does not result in ground water contamination by pesticides. The highest priority need is to address relevant pest problems (insects, nematodes, pathogens, and weeds) in the Corn Belt States. Nevertheless, a plan for all 50 States and the various territories and possessions is needed."

Focus for the Component was provided via a presentation by A. L. Christy (see agenda) as well as accessing other documents (Williams et al. 1988, U. S. Environmental Protection Agency 1987, USDA Economic Research Service 1989). Consequently, the following preliminary report emphasizes midwestern states but deals in general with other areas of

contamination. In fact, concern over pesticide contamination in ground water will provide opportunities to implement an array of non-chemical approaches for managing pest populations.

STATUS OF SCIENCE AND TECHNOLOGY

There are many publications documenting the science and technology of biological control and other biologically-based methods for controlling pests. An important review of biological control was published under the title "Biological Control in Crop Production" (Papavizas, ed., 1981). This book was an outcome of an interdisciplinary symposium, but biological control was defined in a narrow sense, i.e., only the use of biological agents to implement biological control was discussed. In 1985, Hoy and Herzog chaired a symposium "Biological Control in Agricultural IPM Systems." The resultant reference was among the first to focus specifically on the role and status of biological control within the context of agricultural IPM systems. Nevertheless, biological control was defined as the use of biological agents in importation, augmentation, or conservation programs to control pests.

The scope of biological control was dramatically expanded in a briefing document (Research Briefing Panel on Biological Control in Managed Ecosystems, 1987) where the panel defined biological control as "the use of natural or modified organisms, genes, or gene products to reduce the effects of undesirable organisms (pests), and to favor desirable organisms such as crops, trees, animals, and beneficial insects and microorganisms." Cook (1988) simplified this definition to read the use of natural or modified organisms, genes, or gene products to reduce the effects of pests and diseases. The only control methods excluded from Cook's definition of biological control included the use of tillage, open-field burning, heat treatment, and other physical methods, and the use of synthetic chemical pesticides to eliminate pests or reduce their effects.

Priorities were often established for research in the above documents, and recommendations were articulated. More specifically, several workshops have been conducted since about 1976 to improve the focus and coordination of biological control research as well as to develop pathways for implementing biological control. Results of a broadly based workshop "Biological Agents for Pest Control: Status and Prospects" (USDA 1978) were published. This workshop was unique in that it involved the U. S. Department of Agriculture, Land Grant Universities, State Departments of Agriculture, and the Agricultural Research Institute. Other workshops have been agency oriented (USDA, Cooperative States Research Service, 1983, USDA, Agricultural Research Service, 1984, and King et al. 1988).

The ESCOP (Experiment Station Committee on Organizational Policy, Working Group on Biological Control, 1988) succinctly summarized the concept of biological control, illustrated examples of biological control, and recommended a National Biological Control Initiative. Some examples of biological control and other non-chemical methods that might be used to control pests which cause pesticide applications resulting in ground water contamination are as follows:

* Numerous effective parasites and predators have been imported and established on a range of citrus pests, often reducing these pest populations to sub-economic levels. The most outstanding example was control of the cottony-cushion scale by the introduced lady beetle *Icerya purchasi* in 1900. In the 1970s, two parasites, *Amitus hesperidum* and *Encarsia opulenta*, were imported and released into Florida and Texas. They completely controlled the citrus blackfly (Dowell et al. 1981; Summy et al. 1983) until more recently, when, the blackfly escaped biocontrol in Texas, which has been attributed to decline in parasitoid populations as a result of insecticidal drift. In Texas, aldicarb is being used to control blackfly.

There are opportunities for importing, establishing, and distributing effective natural enemies on arthropod pests, viz., corn rootworm, Colorado potato beetle, European corn borer, green peach aphid, and mirids against which pesticide applications may result in ground water contamination.

* Since 1945, about 50 species of biological agents have been introduced into the U. S. for control of 30 weed species. Seventy percent of the introduced agents have established and eight species of weeds are controlled in one or more areas of their range.

* The propagation of predators and parasites to augment their populations in the field is a proven method for controlling their host (pest) populations. This technology has been commercialized for controlling the two-spotted spider mite and greenhouse whitefly in glasshouses as well as California red scale and mealybug in citrus. Other parasites and predators such as *Trichogramma spp.* and the common green lacewing are often sold to the public. Arrangements have been made through the New Jersey Department of Agriculture to propagate and distribute *Edovum puttleri* for control of the Colorado potato beetle and *Pediobius foveolatus* for control of the Mexican bean beetle.

Expansion of this technology is constrained by our ability to economically mass produce, package, and distribute quality predators and parasites. The Colorado potato beetle, green peach aphid, and European corn borer may be controlled by this approach.

* Two nematodes, *Neoplectana carpocapsae* and *Romanomermes culicivorax*, have been commercially propagated and marketed to control insect pests. Expansion of this technology has been slowed because of the lack of economic feasibility and complexity related to using the product. Nematodes have been discovered attacking the corn rootworm and Colorado potato beetle.

* Over 10 different bacteria, viruses, and protozoans have been registered and commercially cultured and distributed for control of caterpillar pests, Japanese beetle, grasshoppers, mosquito larvae, and the pine sawfly. There is the potential for controlling several of the arthropod pest species cited in this report with microbial insecticides, particularly genetically improved strains (conventionally selected and

genetically engineered).

* Two fungi have been registered with the EPA and successfully marketed for the control of weeds. Abbott Laboratories markets *Phytophthora palmivora* as DeVine for control of stranglervine in Florida citrus groves and the Upjohn Company markets *Colletotrichum gloeosporioides sp. aeschynomene* as Collego to control jointvetch in

Arkansas rice fields (Templeton, 1988). Mycoherbicides can be developed for controlling individual weed species in corn and soybeans, but mixtures will be required to control a broad spectrum of weeds.

* Numerous microbes have been discovered and augmented for control of soil-borne pathogens. The mechanisms by which these organisms suppress plant pathogens vary, but generally involve either antagonism, competition, and/or direct parasitism. Examples of commercial application are few. Crown gall of shrubs and certain fruit trees is controlled by dipping bare-root transplants into a suspension of cells of the avirulent antibiotic-producing strain K84 *Agrobacterium radiobacter*, which then protects the roots against infection by the virulent antibiotic-sensitive *A. tumefaciens* (Kerr 1980).

* Judicious use of pesticides with treatments based on established economic thresholds is economically and environmentally justified. Moreover, naturally occurring biological control agents are spared. These agents have been shown to suppress target pests as well as nontarget pests. An example of the consequence of killing natural enemies is the inducement of damaging *Heliothis* populations by foliar applications of insecticides for control of the boll weevil or plant bugs in cotton (King 1986). Likewise, the use of fumigants applied to soils is likely to reduce populations of nontarget mycorrhizal fungi and rhizobia and the use of fungicides to the foliage may reduce populations of epiphytes. Selective pesticides are available that minimize the mortality of certain biological control agents, and selectivity can be enhanced through precise placement of the material.

* Rotating between unrelated crop species often disrupts the cycle of pest species. Pest microbe decline results from a gradual increase in populations of plant parasitic nematodes, root-infecting fungi, and other soil-inhabiting pests and pathogens favored by the crop (Cook 1984). For example, "take all" fungus of wheat is suppressed by preceding the winter wheat crop with a pea or lentil crop. Pest nematodes have been suppressed by planting trap crops, e.g., *Crotalaria spectabilis*, or alternating susceptible with resistant varieties of soybean (Cook 1988). Selected weed species may be suppressed by rotation. A corn-soybean rotation is widely (40%) used in the Midwest to suppress corn rootworm populations, but because of an extended diapause the northern corn rootworm is less vulnerable to a one-year rotation than the western corn rootworm.

* Planting of cultivars resistant to pests is a vital part of integrated pest management.

Host plant resistance is often compatible with the use of natural enemies. For example, damage by the greenbug to barley and sorghum was greatly reduced by the combined effects of resistant varieties and the parasite, *Lysiphlebus testaceipes*, compared to the use of either tactic alone (Schuster and Starks 1975; Starks et al. 1976). Corn breeding lines have been developed that possess large root systems, which impart some tolerance to the corn rootworm (Klassen 1988). Numerous lines of soybeans have been developed that possess resistance to nematodes. Likewise, foliar pathogens are often controlled in plants by the development of resistant lines, but breeders have been less successful in the development of plants resistant to soil-borne pathogens. Genetically engineered resistance is exemplified in the incorporation of the toxin gene from *Bacillus thuringiensis* in tobacco leaves for control of leaf-feeding caterpillars.

* Although the technical feasibility of biologically controlling nematodes has not been demonstrated, this is an important line of research. Bacteria, parasitic on nematodes, have been cultured but mass production methodology needs to be developed. Fungal parasites have been found attacking the soybean cyst nematode.

* Other non-chemical methods for controlling pests include habitat management to favor a biological control agent, the use of behavioral chemicals such as the sex pheromone of the pink bollworm to disrupt mating, the sterile insect release technique, and tillage for weed control.

USDA Ground Water Quality - ARS Biological Control Action Plan

NEMATODES

Introduction

Events that led to the recognition of plant parasitic nematodes as major crop pests later figured heavily in concerns about the future of nematode control. The discovery of the relatively cheap soil fumigant D-D in 1941 and soon afterwards the discovery of EDB and DBCP helped bring plant nematology into prominence. Increase in crop production following the use of these soil fumigants clearly pointed out the serious damage to many crop plants caused by several nematode species. Because of their effectiveness against a broad spectrum of nematodes, these soil fumigants rapidly gained acceptance by growers.

Later, the nonfumigant nematicides begin to emerge. Most of these materials were carbamate an organic phosphate. Although somewhat less effective against a broad range of nematodes, but because of their insecticidal properties, these nonfumigants were readily accepted by growers and used in an array of crop management systems.

Because of their effectiveness, chemical nematicides were heavily relied upon for 35-40 years for controlling nematodes. This widespread acceptance of chemical nematicides as primary nematode control agents caused very little attention to be devoted to developing alternative nematode control practices.

The awareness of the hazards of pesticidal chemicals begin to cause serious concerns about the safe use of these nematicides. By the mid-1980's several of the most effective and widely used nematicides were banned from use. The impact of the loss of these most effective nematicides is still being felt by growers as no alternative nematode control procedures have yet emerged. However, the loss of these nematicides did draw attention to the need to explore alternative means of controlling plant parasitic nematodes.

In retrospect, it is painfully obvious that from the beginning chemical nematicides represented a real threat to the environment and to human health. Clearly such properties as acute animal toxicity, mobility, water solubility, and persistence that make a chemical a good nematicide also makes it a prime candidate for ground water contamination and a danger to human health. Application technology which involves the injection of fumigants 6 inches into the soil or the incorporation of nonfumigants in the top 6 inches of soil added further to their potential for ground water contamination. Thus, it appears likely that the loss of effective nematicides will continue until few are left or until new formulation and/or application technology make them safer to use. Obviously, there is an urgent need to develop alternative methods of controlling plant parasitic nematodes.

Development of Alternative Methods

The loss of several of the most widely used nematicides and the severe limitations placed on the use of others has caused renewed interest in biological control of nematodes. Although

not a new concept in nematode management, biological or biologically based means of reducing nematode populations to noneconomical levels has recently gained considerable popularity as alternative methods of managing plant parasitic nematodes.

Status of Science and Technology

Numerous microbes have been shown to affect nematodes in one way or another in agricultural soils. The most notable of these have been soil fungi and bacteria. Consequently, most of the research on biocontrol of nematodes has involved these two groups of organisms.

Fungal parasites. Early research focused on nematode trapping fungi. The mechanism by which these fungi trapped and destroyed nematodes is easily demonstrated in the laboratory. However, this technology has been difficult to transfer to field conditions. Consequently, nematode trapping fungi have not made a impact on biological control of nematodes.

More recent studies of fungi as biological control agents of nematodes have involved attempts to isolate fungal parasites, culture them, and reinfect nematodes. Several important fungal parasites or pathogens of nematodes have emerged from these studies. Most notable among these are *Nematophthora gynophila* that attacks immature females of the cereal cyst nematode, *Hirsutella rhossiliensis* that attacks various vermiform stages of nematodes, *Verticillium chlamydosporium* that parasitizes eggs of some *Heterodera* spp., and *Paecilomyces lilacinus* that parasitizes eggs of root-knot nematodes. Other significant fungal parasites of nematodes that have been identified are *Dactylella oviparasitica* and *Meria coniospora*. Although proven effective in reducing nematode populations, none of these fungi have yet been commercialized as biological controls of plant parasitic nematodes.

Bacterial parasites. The most notable of the bacterial parasites of nematodes is *Pasteuria penetrans*. Although proven effective against root-knot nematodes, problems in mass producing this bacterium has so far limited its development as a biological control agent.

Host resistance. With the declining availability of nematicides, the use of host resistance, a biologically based means of nematode control, has also gained in popularity. Host resistance is commercially available for a number of important crop-nematode combinations but for many important nematodes resistance is currently nonexistent. Because of its effectiveness, low input, and its compatibility with the environment, host resistance will likely emerge as a leading nematode management tool.

Recent approaches. More recent approaches to developing biological control of nematodes has involved studies of suppressive soils, rhizosphere bacteria, opportunistic soil fungi, chitin degrading fungi, and fungal metabolites that are toxic to nematodes. The secrets of these phenomena and their possible importance in biological control of nematodes have yet to unfold.

NATIONAL PLAN TO REPLACE NEMATICIDES

MID-WEST INITIATIVE

CORN: Only limited amounts of insecticides/nematicides are used on corn in the Mid-West solely for nematode treatments. However, the most commonly used of these chemicals for insect control are also known to reduce nematode populations and therefore most likely provide a secondary control for nematodes. If these insecticides/nematicides (carbofuran, terbufos) are removed from use as insecticides for control of insects (corn root worm, cutworms, European corn borer), then it is probable that nematode populations will increase to damage causing levels. To manage these nematode populations a systems approach must be developed that does not use groundwater contaminating chemicals. The nematodes most commonly found attacking corn in the Mid-West are *Pratylenchus spp.* (root-lesion nematodes), *Longidorus spp.* (needle nematodes), *Trichodorus spp.* (stubby root nematodes), and *Tylenchorhynchus spp.* and *Quinisulcius spp.* (stunt nematodes).

SOYBEAN: In the Mid-west, the most common nematode pest, the soybean cyst nematode *(Heterodera glycines)* is controlled most often by resistant varieties of soybean. However, this pest has rapidly spread into all the Mid-West states in recent years and is known for at least five different resistant-breaking races. Many areas no longer have available resistant cultivars for some races and are relying more and more on nematicides. If all available nematicides were removed from use in the Mid-west, soybean losses would most certainly increase. To manage these pests without groundwater contaminating chemicals, new management strategies must be developed. Other species of nematodes, such as *Meloidogyne spp.* (root-knot nematodes) and *Pratylenchus spp.* (lesion nematodes), with the latter being the most damaging, have been found infesting soybeans in the Mid- West and should be considered in new management strategies, also.

POTATO: Potatoes in the Mid-West are greatly affected by nematodes. Yield loss on potato is compounded by a synergistic interaction with the lesion nematode, *Pratylenchus penetrans* and the fungus, *Verticillium dahliae*; the two together being responsible for the disease, Early Dying of Potato. Other species of *Pratylenchus spp.* and *Verticillium spp.*have been implicated in potato yield losses but not as severe a loss as in the above mentioned complex. Therefore, a reduction in nematicides (aldicarb) or fumigants (Telone) that affect both fungi and nematodes, would result in increased yield losses in the potato growing areas of the Mid-West. Other nematodes such as *Meloidogyne spp.* (root-knot nematodes) and *Ditylenchus spp.* (stem and bulb nematodes) can cause severe damage to potato but are not a widespread as lesion nematodes. New management strategies to reduce nematode levels without nematicides must take into account fungal interactions.

PLANT DISEASES

INTRODUCTION

Of the plant pathogens that afflict the more than 1200 cultivated plants in the U.S., no group is more insidious and unpredictably destructive than the group that enters the plant through the root system or survives in the soil. Soilborne plant pathogens play a major role in the root disease complex causing damping-off, root rots, seedling blights, and wilts on many important field and horticultural crops. A small group of soilborne diseases is kept under a fair degree of control with the use of crop rotations, soil management, or tolerant cultivars. There remains, however, a large number of soilborne pathogens, some of which attack only a few kinds of plants, and others which attack numerous kinds, that either have not been brought under any significant degree of control by any means or are controlled by fungicides and broad spectrum fumigants.

With soilborne plant diseases there is always the possibility of water pollution when pesticides, especially broad spectrum biocides or fumigants such as methyl bromide, chloropicrin, Vapam, Vorlex, Busan 1020, Mylone, Telone, GR Simplot and others are applied to soils as control measures. A good proportion of pesticides applied to the foliage also ends up on or in the soil. Such pesticides may be applied with water or reach water indirectly through runoff from the soil surface. Also, the occurrence of heavy rainfall before pesticides are absorbed to the surface of soil particles may result in contaminated runoff. Two fungicides, PCNB and chlorothalonil, have been detected in ground water (Williams et al. 1988). Byproducts of broad spectrum fungicides and fumigants may also end up in ground water. It is, for instance, known that the active ingredient of many fumigants, methylisothiocyanate (MIT), reacts with soil inorganic nitrogen to form thioureas which can get into ground water and which are known to be carcinogenic (Hughes, 1960). In addition, broad spectrum soil fungicides and fumigants are liable to create three other possible environmental hazards, namely destruction of nontarget beneficial organisms, development of resistant strains of plant pathogens, and deposition of residues that magnify in food chains.

ASSESSMENT OF CURRENT CHEMICAL CONTROL PRACTICES

The fungicides and fumigants that are expected to have the greatest proclivity for contaminating ground water are those that are used in large amounts to control soilborne plant pathogens. Listed below are some of the most common soil pesticides that are used in this fashion and the crops to which they are applied.

I. Potatoes

1. Metham sodium (Sodium N-methyldithiocarbamate, Vapam, Busan 1020) 40-50 ga/A, occasionally 70-80 ga/acre by larger growers.
2. GR Simplot (Generic MIT) 40-50 ga/A
3. Telone C-17 (nitrotrichloromethane + chloropicrin) 50-60 ga/A
4. Telone + Vapam/50 - 75 ga/A

5. PCNB (Pentachloronitrobenzene) 10-20 lbs/A
6. Vorlex (MIT + 1,3-dichloropropene + other chlorinated hydrocarbons) 30-40 ga/A
7. Telone (Dichloropropene) 40-50 ga/A
8. Captan 0.75 - 1.44 lbs/A
9. Maneb 1.0 lb/A
10. Rovral 2.0 lbs/A
11. Ronilan 1-2 lbs/A
12. Chlorothalonil 1-2 lbs/A

II. Specialty Vegetables (lettuce, onion, melon, tomato, eggplant)

1. Vorlex 30-40 ga/A
2. Vorlex + chloropicrin 15-40 ga/A
3. Metham sodium 40-50 ga/A
4. Telone C-17 30 ga/A
5. Dazomet (Micofume) 20-40 ga/A

III. Peanuts

1. PCNB 10.0 lbs/A
2. Chlorothalonil 1.2 lbs/A

IV. Cotton

1. Captan + PCNB 1.0 lb each/A
2. Chloroneb 1-2 lbs/A
3. PCNB-Etridiazole 0.5 + 1.5 lbs/A

V. Sugarbeet

1. Benomyl 0.25 lb/A
2. TBZ 3.6 oz/A
3. Chloroneb 3.9 oz/A

DEVELOPMENT OF ALTERNATIVE METHODS

In the light of present-day constraints on the chemical control practices that reduce the impact of plant diseases, and because of the propensity of pesticides, especially those used in soil, to contaminate ground water, biological control has increasingly captured the imaginations of many scientists and of the public in general and it is gaining stature as a possible practical means of replacing, or reducing the use of some fungicides and fumigants.

STATUS OF SCIENCE AND TECHNOLOGY

There are only two microorganisms registered in the U.S. for biological control of plant diseases, namely *Agrobacterium radiobacter* for control of crown gall and *Peniophora gigantea* for control of stump rot of pine. Commercial use of these organisms has no ameliorating effect on ground water pollution or pollution of any kind. Experimentally, however, the following things have been accomplished:

a. It was shown in New Jersey that it is possible to control *Verticillium* wilt of eggplant in the field by reducing the recommended dose of the fumigant Telone C-17 from 30 to 70 ga/A and supplementing it with *Talaromyces flavus*, a beneficial soil mold.

b. The recommended rate of Vorlex (used for the control of *Fusarium* wilt of melon in Del Marva Peninsula) was experimentally reduced from 40 to 8-10 ga/A with the use of *Trichoderma spp.*strains.

c. A new beneficial mycoparasite, *Sporidesmium sp.* was discovered, which destroys *Sclerotinia sp.*, an important pathogen on lettuce, peanut, potato, bean, sunflower, and many other crops.

d. Two strains of *Gliocladium virens* that gave excellent experimental control of *Sclerotium spp., Rhizoctonia spp.*, and *Pythium spp.* have been isolated from soil.

e. Strains of bacteria (*Pseudomonas spp.*) that experimentally control wheat root rot have been discovered.

f. New strains of *Gliocladium spp.* and *Trichoderma spp.* that are resistant to certain types of pesticides have been developed by mutagenesis.

g. A deep-tank fermentation system to grow beneficial microorganisms and control-release formulations of several microbial disease control agents have been developed.

h. The mechanisms of action of *Talaromyces spp.* on *Verticillium spp., Sporidesmium spp.* on *Sclerotinia spp.* , and *Gliocladium spp.* on *Pythium spp.* and *Rhizoctonia spp.* have been unravelled.

i. An integrated control system to reduce fungicides used to control *Rhizoctonia* fruit rot of cucumber and tomato was developed.

Current Effort

A small number of scientists in ARS and in state agricultural experiment stations are conducting research to develop better strategies for growers to use in managing soilborne plant pathogens to minimize ground water contamination. Below are some of the current

efforts:

1. Development of cultural practices that tend to increase the organic matter content in the soil which, in turn, can absorb some chemicals.

2. Development of conservation tillage practices that tend to decrease the impact of certain soilborne diseases.

3. Experimental approaches to partially or completely replace selected broad spectrum biocides in potato, cotton, specialty vegetables, and small grains by using indigenous microorganisms such as *Gliocladium spp., Trichoderma spp., Talaromyces spp., Sporidesmium spp.,* and beneficial bacteria.

4. Development of modelling systems to study early dying disease of potatoes and the interactions between fungi and nematodes.

Plans

Research is needed to develop effective strategies and models for using biocontrol agents to replace broad spectrum fungicides or for use in combination with reduced levels of pesticides to control selected soilborne diseases and reduce ground water contamination.

1. Research expected to provide practical solutions within five years.

   a. Screen existing and new beneficial fungi and bacteria against selected soilborne plant pathogens which are presently controlled with high amounts of fungicides.

   b. Determine whether beneficial microorganisms are compatible with reduced rates of broad spectrum biocides and if not, use existing strains that are compatible or develop new ones by physical and chemical mutagenesis.

   c. Ascertain the efficacy of using biocontrol agents added after soil fumigation to retard pathogen recovery and reduce the need for further fumigation.

   d. Test the strains in the field in various locations individually and in combination with reduced amounts of fungicides and fumigants.

   e. Estimate the amount of pesticides reaching the ground water by measuring pesticide residues in soil with and without biocontrol treatments.

   f. Develop growth, formulation, and biopesticide application technology to control plant diseases biologically.

   g. Combine biocontrol agents with other non-polluting strategies (tolerant cultivars, organic amendments, cultural practices) to reduce the impact of soilborne plant

pathogens.

2. Fundamental Research

To enhance the chances of success of biocontrol in the future, fundamental research is also needed on the following.

a. Develop novel techniques to quantify and locate microbes and their metabolites (enzymes, antibiotics, etc.) in the plant rhizosphere.

b. Determine rhizosphere interactions between beneficial microorganisms and plant pathogens and develop basic knowledge on colonization of plant roots by beneficial microorganisms.

c. Determine the mechanism of action of important microbial disease control agents such as *Gliocladium spp.* , *Trichoderma spp.*, *Talaromyces spp.*, *Laetisaria spp.*, and bacteria.

d. Identify characters (markers) that can be quickly monitored in order to develop rapid assays to evaluate potential biocontrol strains of fungi and bacteria.

e. Acquire fundamental knowledge of the mode by which microbial pest control agents and their metabolites interact with cells of plant pathogens and how such cells resist invasion and destruction.

f. Identification, regulation and expression of genes in microbes that are responsible for the biocontrol of plant diseases.

g. Determine the factors that affect the expression of the antagonistic phenotype *in situ*.

h. Genetic manipulation (DNA transformations, protoplast fusions) of prokaryotic and eukaryotic beneficial microorganisms to improve their efficacy and increase their resistance to pesticides.

Proposed Plans to Reduce Losses from Specific Plant Diseases and Reduce Use of Fungicides

Soilborne Diseases of Potatoes: Preliminary research has been conducted in Idaho and Beltsville, MD on utilization of *Talaromyces flavus*, *Gliocladium virens*, and *Verticillium tricorpus* for early dying disease control caused by *Verticillium dahliae*. Also, preliminary research has been done in the same areas to control Rhizoctonia black scurf of potato with *G. virens*.

Chemical control with broad spectrum fumigants (see section on Assessment) is the

only control procedure available at this time. Broad spectrum fumigants are used on potatoes in the following areas:

Area	Acreage Treated	Fungicide Used
Central Wisconsin	12,000 - 15,000 acres	See pages 15-16
Pacific Northwest	150,000 - 200,000 acres	" " "
Idaho	30,000 - 35,000 acres	" " "
Michigan	25,000 - 30,000 acres	" " "
Florida	10,000 acres " " ,000 - 15,000 acres	" "
"		

<u>Soilborne Diseases of Specialty Vegetables</u>: (Cucurbits, lettuce, onion, eggplant, tomato) Preliminary research has been done in Centerton, NJ, Salisbury, MD and Beltsville on 1) use of *Sporidesmium spp.* to control *Sclerotinia spp.* on lettuce and *Sclerotium cepivorum* (white root) on onion; 2) utilization of *Talaromyces flavus* to control Verticillium wilt on eggplants (*T. flavus* increased yield on eggplant and allowed a reduction of Telone C-17 from 30 to 7 ga/A); and 3) utilization of *Trichoderma spp.* and *Gliocladium spp.* to reduce the amount of Vorlex used on cucurbits (e.g. Vorlex was used experimentally on melons at 40 ga/A to control Fusarium wilt). Also, preliminarundwater with agricultural chemicals. Iy work has been done on chemigation between P. B. Adams (Beltsville) and Stephen Johnston (Rutgers) to reduce the amount of Metham sodium used on many vegetables in Southern New Jersey.

Fumigants are used extensively to control soilborne diseases of specialty vegetables in the Midatlantic Region, especially in Southern New Jersey, in the Del Marva Peninsula, and in the Rio Grande Valley of Texas (See Section B, Assessment).

<u>Seedling Diseases of Cotton</u>: Seedling diseases of cotton are among the most devastating of those affecting that crop. Seed treatment with fungicides suffices in some areas, but in many parts of the cotton growing belt seedling disease problems are extensive enough to require the addition of 1.5 lb PCNB and 0.37 lb Terrazole per 12,400 linear row feet to the cover soil around the seed. PCNB has been detected in ground water.

Biological Control Implementation Phases

Field Application and Testing of Known Biological Control Agents

The initial objective of this program is to test the efficacy of different strains of the biocontrol agent *Gliocladium virens* as a deterrent to cotton seedling disease pathogens, and thereby to reduce the need for PCNB treatment.

USDA Ground Water Quality - ARS Biological Control Action Plan

WEEDS

Herbicidal control of noxious weeds, such as cocklebur, velvetleaf, pigweed, and foxtails in corn and soybean fields, is the major contributor to pollution of groundwater with agricultural chemicals. In 1986, potential losses due to weeds in these crops was estimated to be ca. $6 billion. Three of the main herbicides used to prevent these losses are alachlor, atrazine, and metolachlor which, at more than 200 million lbs sold, comprised a market value of $751 million in 1987. Thus, this chemical energy is purchased at a cost that prevents losses that would be eight times greater in dollar value. But now an inestimable additional cost of using these herbicides has been found--viz., the contamination of groundwater with these chemicals. Although the major contamination has been found in the Midwestern states, additional problems of groundwater contamination are being found throughout the country. Thus, this is a national problem that demands immediate attention.

Biological control of the weeds is being considered as an alternative to the use of herbicides in areas troubled by groundwater contamination. Research to date, and a few existing examples in agronomic crops, indicate that biocontrol approaches do have the potential to significantly reduce the use of chemical herbicides for weed control in major agronomic crops. However, much research must be done before this goal can be realized. A five-year plan of research is being submitted; but, realistically, little progress in actual practical use of biocontrol for weeds in row crops can be expected before 10 years. If research activities related to biocontrol of weeds were to receive a fraction of the amount (e.g. $50 million) expended by industry to bring one herbicide to the market, then progress could be greatly accelerated.

A total of 16 weeds and at least 37 natural enemies have already been identified as potential targets/biological control projects. One recognized constraint on replacing groundwater contaminating pesticides with biological control alternatives is the narrow spectrum of host range (specificity) of individual biocontrol agents. One potential way to overcome this constraint is to use directed mutagenesis on broad spectrum agents as has been proposed for fungal plant pathogens by Dr. David Sands at Montana State Univ. One possibility is to mutate the organisms so they are dependent on an additive for activity against the weeds; thus, once the control has been accomplished, the controlling organisms will die off without the additive. Hence, a fungus attaching a broad spectrum of targets is rendered safe for many cropping situations.

Dr. Sand's approach is in early stages of investigation and is yet to be proved under wide-scale field testing. Nevertheless, early results, the appeal of the method, and the importance of the groundwater initiative would argue for initiation and support of a high priority ARS research effort toward the development and testing of directed mutagenesis of plant pathogens for biological control of weeds. At the same time, because the directed mutagenesis approach is yet largely unproved and will not be applicable against all targets, research on the more conventional approaches of introduction and augmentation must be given increased support to realize significant progress.

MAGNITUDE OF HERBICIDE PROBLEM

On a national basis, annual losses due to weeds in agronomic row crops have been estimated in 1986 at $8.4 billion; this is the loss in potential yield and quality due to weeds. The major proportion of this loss due to weeds is in corn and soybeans which account for 34% and 38%, respectively, or a total of 71%.

Much of the potential loss in yields due to weeds in major agronomic row crops is, as expected, centered in the Corn Belt states of Iowa, Illinois, Indiana, Ohio, and Missouri. For example, approximately 28% of the total loss attributed to weeds occurs in these Corn Belt states; 45% and 47% of this loss occurs in corn and soybeans (Chandler, et. al. 1984).

In the Southern Coastal Plains states of Alabama, Georgia, Florida, and South Carolina, the weed losses in major agronomic row crops constitute 4% of the total for the Nation. In these states, soils are highly vulnerable to pesticidal contamination of groundwater because they are sandy. Weeds in soybeans at 38% cause the greatest proportion of the loss followed by peanuts and corn at 33% and 22%, respectively (Chandler, et. al. 1984).

Losses due to weeds in major agronomic crops in the Mississippi Delta States of Mississippi, Arkansas, and Louisiana constitute about 6% of the total annual losses for the Nation. In this area the losses attributed to weeds are found in soybeans and cotton at 70% and 29%, respectively.

The remainder of the country includes many other areas vulnerable to contamination of groundwater by pesticides; such areas include the Lake States, the Central Valleys of California, and the Eastern Seaboard. All of the combined regions (other than the Corn Belt, the Southeastern Coastal Plain, and the Mississippi Delta) are subject to losses due to weeds in major agronomic crops estimated at 20% of the total of all weed caused losses in the Nation. Within this loss of 20%, weeds in corn, soybeans, and cotton constitute 45%, 30%, and 20%, respectively.

MAGNITUDE OF HERBICIDE USAGE

Principal crops in the U.S. are planted in 307 million acres. Of these planted acres, 77 million are in corn and 61 million are in soybeans or 25% and 20% of the total, respectively (Agricultural Statistics, USDA, 1987). Ninety-five percent of the corn acres (73 million acres) and 93% of the soybean acres (56 million acres) are treated with herbicides (USDA, Economic Research Service).

Two major herbicides, atrazine and alachlor, are used for weed control in corn and/or soybeans have been implicated in non-point contamination of groundwater in several states (USDA Research Plan for Water Quality, 1989); another herbicide metolachlor, closely related to alachlor, has been found from non-point sources in the groundwater of at least five

states.

The 1987 market sizes of these three herbicides were: alachlor, 85 mil lbs.; atrazine, 79 mil. lbs.; metolachlor, 38 mil. lbs. for a combined market value of $751 million. For the Corn Belt states of Missouri, Iowa, Illinois, Indiana, and Ohio, the usage is shown in Table 1. The total usage per year in these states for these herbicides is: alachlor, 40 mil. lbs.; atrazine, 34 mil. lbs.; and metolachlor, 27 mil. lbs. These amounts comprise 47%, 43%, and 71% of the total nationwide use for alachlor, atrazine, and metolachlor, respectively.

Table 1. The Use of Alachlor, Metolachlor, and Atrazine in lbs./year in the Corn Belt States, ca Mid 1980's[a]

Herbicide Use by Crops

	Alachlor		Metolachlor		Atrazine
Corn Belt State	Corn (million lbs)	Soybeans	Corn (million lbs)	Soybeans	Corn (million lbs)
Illinois	8.5	2.7	5.7	1.6	10.9
Indiana	3.5	3.6	1.1	1.9	8.2
Iowa	9.3	2.1	8.5	1.2	7.4
Missouri	1.3	2.2	.8	1.6	2.3
Ohio	3.0	3.5	2.4	1.9	4.9
TOTAL	25.6	14.1	18.5	8.2	33.7

[a] Source: Gianessi, L. P. and C. A. Puffer. 1988. Use of selected pesticides in agricultural crop production by state. Resources for the Future, 1616 P Street, NW, Washington, D.C. 20036

NATURE OF THE WEED PROBLEMS IN MAJOR AREAS AFFECTED BY HERBICIDAL CONTAMINATION OF GROUNDWATER

A list of 20 weeds is given in Table 2 that denotes the millions of acres within selected crops that were treated with herbicides in 1987. Of those responsive to atrazine and alachlor, the top four broadleaf targets would be cocklebur, velvetleaf, pigweed, and ragweed, while the top two narrowleaf targets would be foxtail and johnsongrass. Because several weed species usually occur in one field, biological control efforts will have to involve a combination of agents or alternative herbicides integrated with biocontrol agents or the use of broad spectrum biocontrol agents that will not affect the crop or that can be used with some scheme to protect the crop against its action.

Table 2. Specific weeds treated with herbicides in selected agronomic crops (1987 acreage) and whether atrazine and/or alachlor were used

Millions of Acres

Weed	Corn	Soybean	Cotton	Rice	Total	Atrazine	Alachlor
Cocklebur	24.9	31.7	5.2	0.5	62.3	+	-
Foxtail	43.2	12.5			55.7	+	+
Velvetleaf	23.5	14.8			38.3	+	-
Pigweed	12.1	12.0	2.3		26.4	+	+
Field bindwd	3.3	9.6	4.5	0.6	18.0	-	-
Ragweed	6.9	6.5			13.4	+	-
Smartweed	5.7	4.9			10.6	+	P
Lambsquarter	6.0	4.9			10.2	+	P
Johnsongrass	2.1	2.9	3.8		8.8	-	P
Quackgrass	7.8				7.8	-	-
Thistles	4.7	1.8			6.5	-	-
Sunflower	5.6	0.4			6.0	-	-
Jimsonweed	2.9	2.9			5.8	+	-
Crabgrass	3.2		1.7	0.3	5.2	-	+
Prickly sida		0.9	2.9		3.8	-	?
Nutsedges	1.7	0.4	0.8	0.4	3.3	-	+
Fall panicum	2.6	0.3			2.9	?	+
Barnyard grass	0.8	0.4	0.8	1.7	2.9	+	+
Coffeeweed		1.5		0.3	1.8	?	+
Sicklepod		0.9			0.9	?	-

BACKGROUND INFORMATION ON BIOLOGICAL CONTROL OF WEEDS

THE AUGMENTATION APPROACH: This approach to biocontrol of weeds involves the use of artificially cultured native (usually) or exotic natural enemies that are present already in the zone of interest but need to be "augmented" or have the normal populations elevated at critical times to effect control of the target weed(s). Examples have historically included the use of insects, fungi, and nematodes.

Selected Examples: The major example of the use of augmented insects involved the mass rearing and release of the moth *Bactra verutana* for control of purple and yellow nutsedge, *Cyperus rotundus* and *C. esculentus*, (Frick, 1985). Another example was mass rearing and artificial dispersal of the moth *Bellura (Arzama) densa* for control of waterhyacinth (O'Leary, 1983).

Many more examples exist regarding the artificial culture and application of endemic plant pathogenic fungi for control of weeds. This use of fungi for weed control has been dubbed

the "mycoherbicide" approach (Templeton, et al., 1979). The first pathogen to be used against weeds was *Cephalosporium diospyri* for control of persimmon, *Diospyros virginiana* in Arkansas (Wilson, 1969). Subsequently, *Phytophthora palmivora* was developed at the U. of Florida as a soil drench for control of *Morrenia odorata* in citrus (Ridings, et al., 1976). This organism was developed jointly by the U. of Florida and Abbott laboratories into a mycoherbicide product called "DeVine^{R}"; this product was the first to be registered for use by EPA in 1981. Another pathogen, *Colletotrichum gloeosporioides f. sp. aeschenomene* was discovered in 1969 and jointly developed in the 1970's and early 1980's by the Agricultural Research Service, the University of Arkansas, and The Upjohn Co. for the control of northern jointvetch, *Aeschenomene virginica*, in rice paddys and irrigated soybeans; this product was licensed by EPA in 1982 and was the first commercially available mycoherbicide for use on an annual weed in an annual crop (Templeton, 1986; Bowers, 1986).

Current Research. The development of the products just mentioned gave impetus to the formation of a Southern Regional Research Committee (S- 136), under the aegis of the Cooperative State Research Service, devoted to sponsoring cooperative research on plant pathogens for biological control of weeds. One of the early projects of this committee was to sponsor an interstate, multi-year experiment on the efficacy of *Alternaria cassiae* for control of sicklepod, *Cassia obtusifolia* (Charudatten, et al. 1986); this experiment was organized by Dr. H.L. Walker, then with the Agricultural Research Service at Stoneville, MS. Subsequently, Mycogen Corp. exclusively licensed the sicklepod pathogen which had been patented by the U.S. Dept. of Agriculture; Mycogen is continuing development of this pathogen under the trade name "CASST. The last (1988) annual report of S-136, contains research summaries reported by about 25 scientists on at least 22 different host-selective fungal pathogens affecting at least 14 different weed species. A recent review lists 33 pathogens (some used in the classical approach) that are or have been researched for control of 24 or more weed species (Charudatten and DeLoach, 1988).

Nematodes have also been considered and used for both classical and augmentative biocontrol programs against weeds. Perhaps the best known nematode project has been the augmentation of *Orrina phyllobia* against silverleaf nightshade, *Solanum elaeagnifolium* in West Texas (Parker, 1986).

Future Research. One criticism of the so-called mycoherbicide approach has been the narrow host range of the pathogens in the face of a broad spectrum of weed pests in most crops (Christy, 1989). One approach to overcome this problem, which is basic to the replacement of herbicides in major crops, has been the genetic manipulation (directed mutagenesis) of fungi for biological control of weeds (Sands, et al., 1989). In this approach, a broad host range pathogen, *Sclerotinia sclerotiorum*, has been treated to produce three classes of mutants: one requiring exogenous cytosine for virulence; one that lacks ability to produce overwintering sclerotia; and one with reduced host range. These mutants of *S. sclerotiorum* are limited to control of broadleaf weeds and so are being tested for use in narrowleaf crops.

Other approaches in the early stages of investigation, are the use of genetic engineering and the use of broad host range non-selective pathogens in crops that have been planted with seed treated with a biological protector (Boyette, 1989).

A third "broad spectrum" approach has been the use of a saprobe fungus, *Gliocladium virens* applied with a medium enriched so as to enhance production of a broad spectrum phytotoxin, viridiol, which is active in the soil against roots of weeds. Crops are protected by judicious placement of seeds (Howell and Stipanovic, 1984; Jones, et al., 1988).

A possible combination of some of these "broad spectrum" methods might provide additional selectivity and efficacy. For example, it might be feasible to combine the "directed mutagenesis" method with the *Trichoderma* seed protection method. Many opportunities for innovation exist.

Another area of research in the augmentation arena has been the use of additives to broaden the host range of host-specific pathogens or to provide diluents for application that will broaden the required microclimate for efficacy. The addition of aqueous plant extracts or pectin was shown to broaden the host range of *Alternaria crassa*, normally used against jimsonweed, *Datura stramonium* (Boyette, 1989). A wax-containing invert (water-in-oil) emulsion as a diluent, applied with an air atomization system was shown to retard evaporation of applied water long enough to support germination of spores of *Alternaria cassiae* and promote infection of sicklepod, *Cassia obtusifolia* (Quimby and Boyette, 1987; Quimby, et al., 1989).

The use of alginates to incorporate fungal mycelia into granules is another method of formulating mycoherbicides for application to the soil (Walker, et al., 1988). Alginate granules amended with nutrients have proved efficacious as carriers for *Fusarium solani f. sp. cucurbitae* applied for control of Texas gourd, *Cucurbita texana* (Weidemann, 1988).

Combining plant pathogens with low dosages of herbicides or growth regulators offers opportunities to broaden the target spectrums of the chemicals or the pathogens. In some cases the combination may control the target weed better than either component above. Examples are 2,4- DB plus *Fusarium lateritium* for control of velvetleaf, *Abutilon theophrasti*, in soybeans (Boyette and Quimby, 1988); and thiadiazuron plus *Colletotrichum coccodes* for control of velvetleaf in soybeans (Hodgson, et al., 1988). Various herbicides can be mixed with *Alternaria cassiae* for control of sicklepod, *Cassia obtusifolia* (Quimby and Boyette, 1986); and trifluralin has been used in combination with *Fusarium solani f. sp. cucurbitae* for control of Texas gourd along with weeds sensitive to the herbicide (Yu, S-M, et al., 1988). *Colletotrichum gloeosporioides f. sp. aeschenomene* has been integrated with herbicides for control of northern jointvetch and other weeds in rice (Smith, 1986). Another possibility for integrated control is combining the effects of insects and microorganisms (Kremer and Spencer, 1989) as exemplified against the target weed, velvetleaf.

THE CLASSICAL APPROACH OR INTRODUCTORY BIOCONTROL:

Selected examples: Biological control of weeds by the introduction of foreign enemies was first used to control prickly pear cactus in Ceylon in 1865. Outstanding successes were obtained against prickly pear in Australia in 1932 after 25 years of importing ca. 50 different species of insects. In the U.S., this method provided good control of lantana, in Hawaii also after more than 50 years of research, and of prickly pear, puncture vine, pamakani and other weeds. Biological control was first attempted in the continental US in 1944 by introduction of a European leaf beetle, previously tested and released in Australia to control the poisonous European range weed, St. Johnswort; complete control was obtained within 5 years after release.

Since then, many insects, and a few plant pathogens and nematodes have been released by both the USDA and the Canadian Department of Agriculture. Worldwide, (as of 1982), 192 insects have been released to control 86 weeds. In a survey made in 1976, when 41 weed project had been attempted, 75% had a measurable degree of success; 9 of them were completely successful in that no further control measures have been required. The present success rate is ca. 25%, lower than previously, because many projects are new and more difficult projects have been attempted. The only crop weeds attempted for control by introduction were the successful control of skeletonweed in wheat fields in Australia in the 1960's using a European rust fungus (later attempted in the US), the recent attempt to control ragweed in row crops in Yugoslavia with a U.S. leaf beetle, and the recent releases of a moth and a mite in the US to control field bindweed.

Introductory biocontrol of crop weeds vs rangeland weeds. Crop weeds generally have been viewed as more difficult introductory biocontrol targets than range weeds for the following reasons: 1) the frequent disturbance of the soil interferes with the life cycle and reproduction of biocontrol agents, 2) pesticides used to control insect pests also kill insect biocontrol agents, 3) the control of one weed species will not eliminate treatments still needed to control the other weed species present, 4) quick control is needed since many weeds increase to damaging levels within 1-2 months after the crop is planted, and 5) many crop weeds are native plants, annuals and/or grasses, all of which have been considered more difficult to control biologically than the perennial weeds of rangelands or wetlands of most of the previous successful projects.

Although all these points are at least partially valid, biocontrol of crop weeds is still possible. Many weeds invade from field borders or spread from weeds remaining in the fields after cultivation or harvest and a reduction of populations of these weeds would reduce the next year's infestation. Pesticide applications can be scheduled to minimize damage to control agents. Most crops have only a few major weed species and biocontrol of more than one, or of all, may be possible. Some insects and plant pathogens can act quickly, as evidenced by the damage they can cause to crop plants under suitable environmental conditions. Several of the most troublesome weeds are perennials especially under no tillage culture; the plants surviving conventional control methods are present and available to biocontrol agents through the entire year. Native plants can be controlled

biologically and grasses probably have enemies sufficiently host specific to introduce, especially plant pathogens. Several of the most important weeds of crops are very difficult and expensive to control by current herbicidal or mechanical methods. Economic benefit can be obtained with biological methods with less than complete control.

Introductory control of native weeds - theoretical considerations. Concern has been expressed recently by some biocontrol workers (Andres, 1981; Pemberton, 1985) that control of a native weed might have unforeseen and harmful repercussions in the ecosystem. These concerns are based on the assumptions that: (1) native species are essential pieces of delicately balanced co-evolved ecosystems that are stable through time, and (2) that native and introduced species play fundamentally different roles in ecosystems. These assumptions follow the ecological theory of Clements (1936). However, Johnson (1985) pointed out that current ecological theory leans much more strongly in the direction pointed by Gleason (1939) that the ecosystem is very resilient, species composition of plant communities is continually changing, and ecosystem stability is more associated with physiognomy and functional processes than with species composition. The roles played by native and introduced plants are not fundamentally different. Thus, the collapse of ecosystems is not an imminent prospect of biocontrol of native plants (Johnson, 1985). This is not to say that the effects of controlling a given weed will not be dramatic from a societal point of view and may greatly affect certain organisms that may be strongly dependent on the weed; these effects should be carefully evaluated on a case by case basis before initiating control.

In the past, excellent control of some weeds has been obtained in some countries by introducing insects from a different species of the weed genus; some workers have even proposed that these would be the best control agents since homeostatic mechanisms that reduce the virulence of the natural enemy have not evolved between the target weed species and the insect (Hokkanen and Pimental, 1984). This theory makes the control of native weeds appear to be more feasible than was previously thought.

Native weeds, controlled by herbicides that are major contributors to groundwater pollution, are cocklebur, yellow nutsedge, all ragweeds, the most damaging species of pigweeds, some foxtails, many morning glories, most smartweeds, some lambsquarters.

Biological control is always incomplete but perhaps adequate. Biological control never gives 100% control of a weed as sometimes is the goal of growers. A change in the perception of "damage" among growers would be very helpful in using biocontrol to reduce herbicidal usage. "Complete" control is not necessary to prevent crop loss; damage occurs only above a certain threshold of a given weed in a given crop at a given time during the growing season. One weed per 10 feet of row probably causes no damage unless it is a seed contaminant. With herbicidal or mechanical methods, control effect is discreet in time--the weed is either killed by the treatment or it recovers and begins growing or reproducing again. With biocontrol, the treatment is continuous in time, and generally of increasing effect through the growing season-a few weeds present are not a source of weed increase but are a source of the natural enemy that exerts an ever- increasing suppression of other weed plants through the growing season.

Overall priority ranking and reasons for priority ranking of weeds for biological control are given in Table 3.

Table 3. Overall priority ranking of weeds for biological control. Priority determined by 1) contribution of weed to groundwater pollution, 2) potential for successful biocontrol (by introduction and augmentative approaches), and 3) amount of crop losses caused.

Rank for biocontrol research	Weed	Herbicide usage (rank)	Crop losses caused (rank) Natl.	Crop losses caused (rank) Southern 13 states	Biocontrol potential Intro.	Biocontrol potential Aug.	Source of biocontrol agents
1	Cocklebur	1	4	3	fair	fair	Arg., US
2	Velvetleaf	3	6	41	fair	fair	China, Arg.,US
3	Bindweed	5	15	36	good	fair	Europe, US
4	Nutsedge	16	9	6	fair	fair	Israel, S. Asia
5	Johnsongrass	9	5	1	fair	fair	Israel, US, Sudan
6	Ragweeds	6	16	12	very poor	fair	US, Arg.
7	Pigweeds	4	1	13	very poor	poor	US, Europe
8	Foxtail	2	2	--	very poor	poor	US
9	Quackgrass	10	14	--	poor	poor	
10	Morningglory	?	8	2	fair	fair	Arg.,US
11	Crabgrass	14	3	29	poor	fair	
12	Leafy spurge	?	?	?	very good	very poor	Europe,China
13	Smartweed	7	11	32	very poor	?	
14	Lambsquarter	8	10	--	poor	?	
15	Thistles	11	17	15	very good	fair	Europe
16	Sesbania	?	11	?	very good	?	Arg., Bol.

Comparison of control methods and implications for pollution of groundwater. Four principal methods may be used to control weeds: mechanical, herbicidal, augmentative biocontrol, and introductory biocontrol. The advantage of mechanical and herbicidal control is their broad spectrum of effect, i.e. all, or most, weeds are killed by one tillage or one application. Machines cause more soil erosion whereas herbicides can be used with no-till or low-till methods that largely prevent erosion. Both are relatively expensive and cost is dependent on the area treated; however, some herbicides cause harmful pollution of surface

and ground water.

Biocontrol is very species specific, does not harm non-target species, causes no pollution, and can be used in no-till agronomic systems. This high specificity is very desirable in some situations (rangelands, wilderness or riparian areas, aquatic sites) where non-weed vegetation is valuable for wildlife, outdoor recreation, etc. In crops, high specificity is a disadvantage, because the remaining weed species still require control.

Augmentative biocontrol increases the effectiveness of naturally occurring control organisms. Like herbicidal and mechanical methods, control is temporary, occurs only where the organisms are applied, and requires periodic treatment of the entire infested area; thus cost is dependent on the area treated. Control can be discontinued 24if need be simply be discontinuing applications. Cost is feasible for many crop situations if plant pathogens are used (which can be mass produced at very low cost) but probably not if insects are used (which are more expensive to mass produce). Cost is usually prohibitive in rangelands, pasture and low-value crops.

Introductory biocontrol depends on the introduction of natural enemies from other areas of the world. Unlike the other methods, the control agents are released at only a few sites from which they increase and disperse naturally and actively search for and destroy the target weed. Control is permanent and cost is independent of the area treated or the duration of treatment. The only cost is that of the research (the producer usually needs to pay nothing) and cost per acre is extremely low if large areas are treated -- it is suitable for extremely low-value-per-acre agricultural systems such as arid rangelands. The method does have disadvantages. It may damage the weed wherever it occurs (including areas and uses where is beneficial), and once established, the organisms can be removed and control stopped only with great difficulty (if at all) if needs change and control is no longer desired. Conflicts of interest between groups who want the weed controlled and groups who consider it beneficial, therefore, must be carefully considered before irretrievable releases are made. Organisms that meet the strict criteria required may not exist that will control every weed.

Almost all of the weeds that elicit the herbicidal control implicated in groundwater pollution are weeds of cultivated crops. Most of these weeds are introduced species, but several important weed
species (and several weeds of species complexes) are native to North America.

Biological control of weeds of crops by the <u>introduction of foreign control agents</u> has only recently been attempted and no cases have yet been successful that would demonstrate that the method is feasible. However, one case during the 1960's was highly successful in a drill crop--that of the control in Australia of skeletonweed (introduced from Europe) in wheat fields with an introduced rust also from Europe. Two other projects have recently been attempted. The first was control of the European field bindweed in the U.S. with natural enemies introduced from Europe; a noctuid moth was released by ARS in Texas in 1987 and a mite in 1989, but establishment is not yet confirmed. The second is control of North American ragweed in Yugoslavia with an introduced leaf beetle from the U.S.; the beetle

was established in 1988 but has not yet dispersed and, of course, control has not yet been demonstrated.

Practical biological control of an agronomic crop weed by augmenting the effectiveness of a naturally occurring control agent has been demonstrated only once. This was the successful control of northern jointvetch in Arkansas rice fields with a native plant pathogen. This project, which was a joint effort by ARS and the University of Arkansas, required ca. 10 years for research and development to reach the point where the product was commercially available to growers. One other project, the control of nutsedge in cotton in Mississippi with the native moth *Bactra verutana* (an ARS project) was technically successful but not economically feasible. The one other successful case, control of strangervine in Florida citrus groves with a native fungus, was in a more stable ecosystem not very comparable to a row- crop situation.

Biological control of weeds in row crops appears to have the technical possibility of success in some, and perhaps many, cases. Insects are known in South America and Europe that are promising control agents for several important crop weeds; additional explorations there and in Asia and Africa would probably reveal many additional insects and plant pathogens that are good candidates as control agents.

Several native plant pathogens are known in the U.S. that are promising control agents for several important crop weeds. Additional pathogens probably can be found and several of the known ones probably can be developed into successful control agents with additional research; however, several of the known pathogens may require genetic modification before use to avoid damage to closely related crop plants or to improve infection and disease development under varying climatic conditions. Experience has demonstrated that many pathogens produce disease under experimental conditions but very few provide consistent disease production under field conditions with 27current technology.

Augmenting the effects of native insects to control weeds is probably too expensive by common mass production and release methods except in extremely high value crops such as floral culture and some vegetables. However, if only inoculative releases were required, such as is used with control of the Mexican bean beetle, such control might be economically feasible.

Can biocontrol of weeds have an impact on groundwater pollution by herbicides? In view of all past experience, we must conclude that biological control of weeds in row crops, to the point where herbicides can be substantially reduced over a wide area, is technically feasible in many cases. In some cases, control of one major weed species would allow a reduction in herbicidal application; in most cases, control of 2 to 3 weeds species would be required. Considerable research progress can be made within the proposed five-year time frame. However, to expect control to the point where groundwater pollution will be substantially reduced within 5 years is not realistic.

This new initiative to control groundwater pollution comes at a time when investment in

biocontrol of weeds research by ARS has been severely reduced (a loss of one-third of the research personnel in the past 5 years) which has caused recent progress to be severely limited. Success in biocontrol of weeds in any one crop will require a substantial increase in research personnel and funding, perhaps of a magnitude to match the $30 - 50 million invested by the chemical industry to produce a new herbicide.Principal crops in the U.S. are planted in 307 million acres. Of these planted acres, 77 million are in corn and 61 million are in soybeans or 25% and 20% of the total, respectively (USDA, 1987). Ninety-five percent of the corn acres (73 million acres) and 93% of the soybean acres (56 million acres) are treated with herbicides (USDA, Economic Research Service, 1989). Two major herbicides (atrazine and alachlor) are used for weed control in corn and/or soybeans and have been implicated in non-point contamination of groundwater in several states (USDA, Research Plan for Water Quality, 1989); another herbicide metolachlor, closely related to alachlor, has been found from non-point sources in the groundwater of at least five states. The 1987 market sizes of these three herbicides were: alachlor, 85 million lbs.; atrazine, 79 million lbs.; and metolachlor, 38 million lbs.. The combined market value was $751 million. For the Corn Belt states of Missouri, Iowa, Illinois, Indiana, and Ohio, the usage is shown in Table 1. The total usage per year in these states for these herbicides is: alachlor, 40 million lbs; atrazine, 34 million lbs.; and metolachlor, 27 million lbs. These amounts comprise 47%, 43%, and 71% of the total nationwide use for alachlor, atrazine, and metolachlor, respectively.

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ARTHROPOD PESTS/INSECTICIDES

In developing this plan, focus has been on major target pests that (1) attack the most important commodities and (2) have been controlled by insecticides/miticides that have appeared in ground water in six major regions of the continental U.S. Some insecticides serve a secondary role in suppressing plant-parasitic nematodes. Therefore as non-chemical control alternatives are developed for arthropod pests, new control approaches may be required for nematodes.

MIDWEST REGION (OH, IN, IL, IA, MI, WI, MN, ND, SD, NB, KS, MO, KY)

This region, generally regarded as the nation's breadbasket, is extensively farmed, and carbofuran, one of the leading pesticides used by farmers there, has been detected in ground waters of several midwestern states. The major crops, corn and soybeans, both use significant levels of agricultural chemicals, but the principal source of ground water contamination appears to be insecticides used in corn, with 35-41% of the surveyed acreage being treated. In the more northern states, there are significant acreage of potatoes which receive insecticide usage. The issue of ground water quality is of prime importance in the Midwest region because nearly 15 million people are served by public water supplies (ground water only) in potentially contaminated counties (Nielsen and Lee, 1987).

CORN: More than 19 million acres of corn in this region were treated with insecticides during 1988. Terbufos (31%), chlorpyrifos (30%), fonofos (13%), and carbofuran (8%) comprised over 80% of the total usage (USDA ERS, 1989). All of these materials have been detected in ground water (Hallberg, 1987). The greatest usage involves applications at planting for control of corn rootworm larvae, but insecticides are also used to control European corn borers and other pests.

Corn Rootworm Complex The corn rootworm complex (CRW), *Diabrotica spp.*, which includes the western, northern, and southern corn rootworms, is the principal insect pest complex on corn in the U.S. Economic losses are estimated to approach one billion dollars annually. Chemical controls cost approximately 250 million dollars annually, and account for over 50% of all insecticides applied in the U.S. The impact of CRW insecticides, especially carbofuran, on ground water contamination, is uncertain, but reduction in the use of soil insecticides for this pest complex would dramatically reduce environmental risk. Several non-chemical approaches for CRW control are available but economic and social factors have limited their acceptance. The objective of the following program is to develop an integrated approach to control CRW populations through the development and application of cultural, biological, and reduced chemical control methods. Emphasis is placed on: (1) establishing cropping practices that will maintain agricultural profitability while managing CRW populations; (2) identifying and developing biological control approaches, especially for larval control; and (3) developing methods to manage adult populations using a minimal input of insecticides through the application of semiochemical bait technology.

European Corn Borer The European corn borer (ECB), *Ostrinia nubilalis*, is one of the primary pests of corn. It was accidentally introduced into the New England area in the early 1900's and moved to the Corn Belt in the 1940's and early 1950's, and eventually southward. The ECB now occurs in almost all corn growing regions east of the Rocky Mountains, which covers approximately 80 million acres. Presently, control of ECB is primarily by host-plant resistance and chemical insecticides, which, for several reasons, are not satisfactorily managing this insect. The more obvious reasons are the lack of germplasm resistant to ECB in pollen-shedding corn and the absence of monitoring techniques for accurate timing of insecticide application. In addition, carbofuran used for population suppression is a groundwater contaminant. During the 1930's and 1940's, several parasitoids were introduced from Europe and Asia to combat the ECB. Few established, the exceptions being *Eriborus terebrans, Macrocentrus grandii*, and *Lydella thompsoni*. Of these three, only *M. grandii* remains in the greater Corn Belt. *Nosema pyrausta*, a microsporidium, is presently the most effective naturally occurring biological control agent. Its presence fluctuates within a given population within a given year, and it is known to be infective to *M. grandii*. The bacterium *Bacillus thuringiensis* is a very efficacious biological insecticide, but it is short-lived due to degradation by environmental factors, primarily sunlight. It is feasible that the ECB can be suppressed by the use of available biological control organisms, resistant germplasm, and the introduction and/or development of other beneficial organisms.

Corn Earworm Management of corn earworm (CEW), *Heliothis zea*, populations in corn does not appear to be a significant cause of ground water contamination in the Midwest.

Cutworms Management of cutworm populations in corn does not appear to be a significant cause of ground water contamination in the Midwest.

SOYBEANS: Management of soybean arthropod pest populations does not appear to be a significant cause of ground water contamination in the Midwest.

POTATOES: Although the total acreage (ca. 336,000 A in 1986) of potatoes in this region does not compare with that of corn, it does represent a significant percentage (ca. 28%) of the total U.S. area in potato production. Moreover, insecticide usage on potatoes is generally intensive, and many detections based on pesticide ground water monitoring in the U.S. involve insecticides used on this crop, particularly problems with aldicarb in New York (Long Island), Wisconsin, and Florida, and with oxamyl in Rhode Island. Because of the close proximity of some production areas to population centers (ca. 2,000 wells contaminated with aldicarb on Long Island), there is a potential human health problem of significant scope. Therefore, it seems appropriate to include biological control efforts against arthropod pests of potatoes as part of the Midwest initiative.

Colorado Potato Beetle: A significant number of detections of aldicarb in ground water are associated with treatments directed at the Colorado Potato Beetle (CPB), *Leptinotarsa decemlineata*, particularly in the Northeastern States. Since it is a native North American

pest, early studies focused on its indigenous natural enemies, the principal species being *Myiopharus doryphorae*, a dipterous larval parasitoid, *Perillus bioculatus*, a predaceous stink bug, and *Lebia grandis*, a coleopteran predator-parasite. Because these natural enemies have not been sufficiently effective to control CPB, recent efforts have been made to use exotic natural enemies of closely related species to control it. Several of these have been imported from Central and South America, but none have become established, presumably because they could not overwinter in temperate growing areas. The most promising species, the egg parasitoid *Edovum puttleri*, was the object of augmentative release trials on potato and eggplant. The eggplant trial was successful and has led to a commercial *Edovum puttleri* release program in New Jersey. The pest still requires intense chemical control on potato. Since ca. 80% of the nation's potato acreage lie north of 40° North Latitude, the most promising approach appears to be the introduction of natural enemies of closely-related species from temperate and high altitude South America. The same objective could be met by developing a diapausing strain of *Edovum puttleri*. Other strategies of lower priority involve augmentation of native natural enemies, use of trap crops, and incorporation of B. t. toxin into plant varieties.

Green Peach Aphid: (GPA), *Myzus persicae*, is a key pest of potatoes, as the species is the primary vector of several virus diseases of potatoes. Current loss, including control costs, due to the major virus, potato leafroll virus, exceeds $125 million annually. At present, control of GPA relies entirely on chemical pesticides, some of which are identified as ground water contaminants. The objective of the biological control program will be to establish effective suppression of GPA by a combination of beneficial agents. This will include introduction and establishment of exotic beneficial agents, development of known pathogenic fungi as biopesticides, and the development, evaluation, and implementation of augmentative utilization of beneficial species in the peach orchard-weed ecosystem in early season. Effective utilization of the above approaches will require improved monitoring technology and an understanding of the contribution of various alternate hosts to the winged GPA populations which move to the potato crop. A thorough understanding of the virus-vector-plant relationships of GPA in the transmission of potato virus is also required.

ALFALFA: Management of alfalfa arthropod pest populations does not appear to be a significant cause of ground water contamination in the Midwest.

FRUIT: Management of fruit arthropod pest populations does not appear to be a significant cause of ground water contamination in the Midwest.

WHEAT: Management of wheat arthropod pest populations does not appear to be a significant cause of ground water contamination in the Midwest.

SOUTH COASTAL PLAIN (NC, SC, GA, FL, AL)

The potential for ground water contamination by pesticides in this region is high because (1) the area's hygrogeological characteristics render it vulnerable, and (2) pesticide usage is high (Nielsen and Lee, 1987). Major crops include corn, soybeans, cotton, peanuts, potatoes, and,

in Florida, citrus.

CORN: Management of corn arthropod pest populations may be a significant cause of ground water contamination in the South Coastal Plain. See Midwest Region ACTARs for control approaches for corn rootworms and European corn borer. Control of other South Coastal Plain arthropod pests is not known to be a significant cause of ground water contamination in this region, with the possible exception of wireworms, bill bugs, and cutworms. Control arrays for these insects may need to be developed.

SOYBEANS: Management of soybean insect populations does not appear to be a significant cause of ground water contamination in the South Coastal Plain.

COTTON: Management of cotton arthropod pest populations does not appear to be a significant cause of ground water contamination in the South Coastal Plain. See Mid-South Region for control approaches for early season pests (plant bugs).

CITRUS: The total acreage (700,000) of citrus in Florida and the sandy soil in combination with the high water table provide the potential for significant ground water contamination. The use of Temik (aldicarb) and Nemacur (femamiphos) as nematicides in citrus has resulted in well contamination in areas adjacent to treated groves. When these materials are applied in citrus, there is a real potential for human health problems. A reduction in the use of soil nematicides would dramatically reduce environmental risk. The use of miticides, insecticides and herbicides in citrus is extensive, and any program that reduces the total use of chemicals would reduce the potential of a human health problem; therefore, it seems appropriate to include biological control of arthropods as part of the citrus initiative.

Above Ground Arthropod Pests (CAGAP) that require use of chemical pesticides are: Citrus rust mite, *Phyllocoptruta oleivora*; six-spotted mite, *Eotetranychus sexmaculatus*; Texas citrus mite, *Eutetranychus banksi*; citrus snow scale, *Unaspis citri*; chaff scale, *Parlatoria pergandii*; citrus blackfly, *Alerurocanthus woglumi*; and other above ground pests. Most of the CAGAP provide excellent candidates for classical biocontrol except for the citrus rust mite. Other non-chemical methods for controlling citrus pests that need to be developed include the use of insect pathogens, behavioral chemicals, and habitat management.

Rootweevil Complex (CRWC): Fullers rose beetle, *Pantomorus cervinus*; little leaf notcher, *Artipus floridanus*; citrus rootweevils, *Pachnaeus litus* and *P. opalus*; and the sugarcane root weevil, *Diaprepes abbreviatus*. Damage is estimated at several million annually. All chemicals that were applied to the soil for larval control have been removed from the market and weevil damage has increased significantly. The use of entomogenous nematodes offer a possible method to manage this weevil complex with no effect on ground water quality. Emphasis is placed on: (1) identifying the most effective nematode species or strains for CRWC management; (1) developing methods to apply this biocontrol agent in citrus; and (1) evaluating control effectiveness in groves.

PEANUTS: The magnitude and extent of ground water contamination attributable to management of peanut arthropod pest populations in the South Coastal Plain could not be determined with the materials available, and need to be determined. See Midwest Region for control arrays for corn rootworms.

POTATOES: See Appendix for appropriate control arrays for European corn borer (1.1.2.1, 1.1.2.5, 1.1.2.6, 1.1.2.8 and 1.1.2.10) and Colorado potato beetle all arrays under 1.3.1).

MID-ATLANTIC AND NORTHEASTERN REGION (VT, NH, ME, CT, MA, RI, NY, NJ, PA, MD, DE, VA, WV)

Agricultural land use is not so extensive in this region as it once was, but there is still an important agricultural economy in the region, even in industrialized states such as New Jersey. Because this region is highly populated, there is a high diversity of crops produced, and there is significant insecticide usage, particularly on potatoes, soybeans, and corn.

POTATOES: Control of arthropod pests of potatoes appears to be a major cause of ground water contamination in this region. Control arrays for these pests are presented for the Midwest Region (1.3) in the Appendix.

FRUITS AND VEGETABLES: Management of fruit and vegetable arthropod pest populations does not appear to be a significant cause of ground water contamination in this region.

SOYBEANS: Management of soybean arthropod pest populations does not appear to be a significant cause of ground water contamination in this region, with the exception of the Mexican bean beetle.

Mexican Bean Beetle In the Northeastern States, the Mexican bean beetle (MBB), *Epilachna varivestis*, is the top-ranked soybean pest (USDA, 1985). During the survey period, 11% of the soybean acreage was treated with aldicarb or carbofuran to control this pest. Classical biological control efforts in progress against this pest have not yet proven successful, because none of the imported natural enemies, all larval parasitoids, have become established, presumably due to the absence of overwintering hosts. One of them, *Pediobius foveolatus*, has been utilized in an augmentative approach on ca. 8% of soybean acreage in MD and DE, and 30% in VA. Another major objective of the biological control program should be the establishment of an effective egg parasitoid in the Northeastern States. A potential candidate is an *Ooencyrtus species* that attacks eggs of Epilachninae in South Africa. *Ooencyrtus spp.* often overwinter as adults; it is therefore possible that this species could overwinter in the region and reduce populations of the target pest, giving concomitant reductions in use of aldicarb and carbofuran.

CORN: Management of corn arthropod pest populations may be a significant cause of ground water contamination in this region. See Midwest Region ACTARs for control approaches for corn rootworms and European corn borer.

MID-SOUTH REGION (MS, LA, AR, TN, MO [bootheel])

Areas of potential ground water contamination from pesticides in this region are concentrated in western Tennessee, the northern half of Louisiana, and along the Mississippi River in the remaining states (Nielsen and Lee, 1987). Major crops in this region include cotton, soybeans, rice, and corn.

CORN: See control array for European corn borer in Midwest Region (1.1.2).

SOYBEANS: Management of soybean arthropod pest populations does not appear to be a significant cause of ground water contamination in this region.

COTTON: In 1988, insecticides were applied on 66% of the cotton acreage nationwide, but usage was particularly high in Mississippi, 95% (USDA ERS, 1989). Soil applications of aldicarb appear to be a source of potential ground water contamination.

Plant Bugs *Lygus spp.* and *Pseudatomoscelis seriatus* are serious early season cotton pests in parts of the Cotton Belt. In the Mid-South, *Lygus lineolaris* and thrips are the targets of soil-applied aldicarb treatments. These in-furrow treatments represent a high potential for reaching ground water, especially in sandy soils. Potential alternatives to aldicarb usage involve development of nectariless germplasm and its incorporation into commercial cultivars, improved technology for plant bug monitoring, and management of plant bugs in early season wild host plants. Also, two European parasitoids have been recently established in the Northeast, and would be valuable additions to the plant bug natural enemy complex in the Mid-South.

RICE: Management of rice arthropod pest populations does not appear to be a significant cause of ground water contamination in the Mid-South Region, with the possible exception of the rice water weevil, *Lissorhoptrus oryzae*, for which carbofuran is the primary insecticide used for control. Control arrays may have to be developed for this insect.

THE WEST (CA [northern], OR, WA, ID, MT, WY, CO, UT, NV)

POTATOES: Control of arthropod pests of potatoes appears to be a major cause of ground water contamination in the West. Control arrays for these pests are presented for the Midwest Region (1.3) in the Appendix.

ALFALFA: Management of alfalfa arthropod pest populations does not appear to be a

significant cause of ground water contamination in the West.

FRUITS AND VEGETABLES: Management of fruit and vegetable arthropod pest populations does not appear to be a significant cause of ground water contamination in the West.

WHEAT: Management of wheat arthropod pest populations does not appear to be a significant cause of ground water contamination in the West.

CORN: Control of arthropod pests of corn may be a cause of ground water contamination in the West. Control arrays for these pests are presented for the Midwest Region (1.1) in the Appendix.

SOUTHWEST (CA [southern], NM, AZ, TX, OK)

FRUITS AND VEGETABLES: Management of fruit and vegetable arthropod pest populations does not appear to be a significant cause of ground water contamination in the Southwest.

COTTON: Control of arthropod pests of cotton may be a cause of ground water contamination in the Southwest. Control arrays for some of these pests are presented for the Mid-South Region (4.3).

ALFALFA: Management of alfalfa arthropod pest populations does not appear to be a significant cause of ground water contamination in the Southwest.

CITRUS: The magnitude and extent of ground water contamination attributable to management of citrus arthropod pest populations in the Southwest could not be determined with the materials available, and needs to be determined. Aldicarb use to treat for nematodes, citrus rootstock weevil, and citrus decline has been detected in Florida groundwater. Aldicarb is used in the Lower Rio Grande Valley for control of the citrus blackfly in citrus.

The total acreage (700,000) of citrus in Florida and the sandy soil in combination with the high water table provide the potential for significant ground water contamination. The use of Temik (aldicarb) and Nemacur (femamiphos) as nematicides in citrus has resulted in well contamination in areas adjacent to treated groves. When these materials are applied in citrus, there is a real potential for human health problems. A reduction in the use of soil nematicides would dramatically reduce environmental risk. The use of miticides, insecticides and herbicides in citrus is extensive, and any program that reduces the total use of chemicals would reduce the potential of a human health problem; therefore, it seems appropriate to include biological control of arthropods as part of the citrus initiative.

CORN: Management of corn arthropod pest populations may be a significant cause of ground water contamination in the Southwest. See Midwest Region ACTARs for control approaches for corn rootworm (1.1.1). Control of other corn arthropod pests is not known to be a significant cause of ground water contamination in the Southwest, with the possible exception of southwestern corn borer. Control arrays for this insect may need to be developed.

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APPENDIX

USDA Ground Water Quality - ARS Biological Control Action Plan

AGENDA

Ground Water Quality and Biological Control
Beltsville, Maryland
May 15-18, 1989

Moderator: Edgar G. King

May 15

1:30 p.m. - Introduction - E. G. King

1:45 p.m. - Introduction and overview of Ground Water Quality Initiative - C. R. Amerman

2:30 p.m. - Pesticide usage and ground water contamination A. L. Christy

3:30 p.m. - Planning approach and Report Format - C. A. Onstad

5:00 p.m. - Adjourn

May 16

8:00 a.m. - Designate priorities and assign work teams

10:00 a.m. - Prepare team reports

May 17

8:30 a.m. - Review progress on team reports

10:00 a.m. - Continue preparation and finalize draft of team reports

May 18

9:00 a.m. - Submit and present team reports

1:00 p.m. - Adjourn to executive session to merge reports R. S. Soper, E. G. King, others

USDA Ground Water Quality - ARS Biological Control Action Plan

ATTENDEES

C. R. Amerman
K. D. Biever
A. L. Christy
J. R. Coulson
C. J. DeLoach
R. M. Faust
R. W. Fuester
M. H. Greenstone
C. R. Howell
R. L. Huettel
J. J. Jackson
E. G. King
L. C. Lewis
C. A. Onstad
G. C. Papavizas
P. C. Quimby, Jr.
J. M. Schalk
R. S. Soper

TEAM COMPOSITION

Arthropod Pest Control

K. D. Biever, J. R. Coulson, R. W. Fuester, M. H. Greenstone, J. J. Jackson, L. C. Lewis, and J. M. Schalk

Weed Pest Control[1]

C. J. DeLoach and P. C. Quimby, Jr.

Plant Pathogen Pest Control

C. R. Howell and G. C. Papavizas

Nematode Pest Control[2]

R. L. Huettel

[1]Other scientists invited included T. D. Center and R. J. Kremer

[2]Other nematologist invited was W. B. Brodie

USDA Ground Water Quality - ARS Biological Control Action Plan

NEMATICIDE REPLACEMENT PLAN

Nematode Control on Corn Implementation

Lead Array:

1.1 Develop models to predict population dynamics, life cycles, survival, and damage functions of plant parasitic nematodes on corn in the Mid-West.

1.2 Establish new rotation and cultural practices to reduce nematode populations on corn in the Mid-West.

1.3 Conduct surveys to determine bacterial and fungal biocontrol agents that could be used to reduce nematode populations on corn in the Mid-West.

1.4 Development of resistant cultivars of corn to plant parasitic nematodes in the Mid-West.

Safeguard Array:

1.5 Select naturally occurring fungal and bacterial enemies and test for degree of control for major nematode pests.

Optimizing Array:

1.6 Develop bioassays to test for semiochemicals that affect some part of the nematodes life cycle that could be used alone or in conjunction with a biocontrol agent.

Supplementary Array:

1.7 Genetically manipulate identified fungal and bacterial biocontrol strains for temperature tolerance, competitiveness, fungicide resistance.

1.8 Identify genes for resistance to nematodes in corn to be incorporated into other corn cultivars.

Soybean Nematode Implementation Plan

Lead Array:

2.1 Development of resistant cultivars that prevent low level reproduction of soybean cyst nematodes.

2.2 Conduct surveys to determine fungal and bacterial biocontrol agents that could be used to reduce nematode populations on soybeans in the Mid-West.

2.3 Development knowledge of bioregulators, such as semiochemicals, that can be used alone to disrupt some part of the nematodes life cycle or in conjunction with a biocontrol agent to enhance control.

Safeguard Array:

2.4 Begin explorations for naturally occurring fungal and bacterial biocontrol agents.

Optimizing Array:

2.5 Develop biochemical and molecular techniques to rapidly separate races of soybean cyst nematodes.

2.6 Identify fungal and bacterial biocontrol agents for abilities to reduce nematode populations.

Supplementary Array:

2.7 Identify genes for resistance to nematodes in soybeans.

2.8 Isolate proteins and use restriction analysis to identify unique markers that may be specific in races of soybean cyst nematodes.

2.9 Genetically manipulate identified fungal biocontrol strains for temperature tolerance, competitiveness, and fungicide resistance.

2.10 Genetically manipulate identified bacterial biocontrol agents for host range increase, virulence, and survivability.

Potato Nematode Implementation Plan

Lead Array:

3.1 Develop potato cultivars that are resistant to both *Pratylenchus spp.* and *Verticillium spp.*

3.2 Conduct surveys to determine fungal and bacterial biocontrol agents that could be used to reduce both nematode and pathogenic fungal populations.

Nematodes on Corn

	Year 1	Year 2	Year 3	Year 4	Year 5
Lead Array					
1.1 Develop Model	Collect Data	Collect Data	Collect Data	Produce Model	Begin Test of Models
1.2 Rotation	Establish Plots	Collect Data	Collect Data	Collect Data	Collect Data
1.3 Biocontrol	Conduct Survey	Test Organisms	Test Organisms	Test Organisms	Test Organisms
1.4 New Cultivars	Establish Plots	Collect Data	Collect Data	Collect Data	Collect Data
Safeguard Array					
1.5 Select Biocontrol Organisms	Establish Plots	Collect Data	Collect Data	Test Strains	Release New Strains
Optimizing Array					
1.6 Develop Bioassays	Isolate Compounds	Identify Compounds	Test Compounds	Test Compounds and Biocontrol	Release New Compounds
Supplementary Array					
1.7 Genetically Manipulate Biocontrol Agents	Manipulate Agents	Select New Strains	Field Test	Field Test	Release New Strains
1.8 Identify Genes in Corn	Identify Genes	Make Selections/ Isolate Genes	Introduce Into New Varieties	Greenhouse Test	Field Test

Nematodes on Soybeans

	Year 1	Year 2	Year 3	Year 4	Year 5
Lead Array					
2.1 New Cultivars	Establish Plots	Collect Data	Collect Data	Collect Data	Release New Varieties
2.2 Biocontrol	Conduct Surveys	Greenhouse Test Organisms	Field Test Organisms	Field Test Organisms	Field Test Release New Strains
2.3 Bioregulators	Establish Bioassay	Isolate Compounds	Identify Compounds	Test Compounds	Field Test
Safeguard Array					
2.4 Select Organisms	Conduct Surveys	Test Organisms	Test Organisms	Test Organisms	Test Organisms
Optimizing Array					
2.5 Gel Electrophoresis	Identify RLFP	Develop Molecular Probes	Identify Genes	Identify Genes	Identify Genes
2.6 Biocontrol	Establish Plots	Field Test	Field Test	Field Test	Release Strains
Supplementary Array					
2.7 Select New Cultivars	Use Molecular Techniques	Identify Genes	Isolate Genes	Insert Genes	Test Product
2.8 Fungal Biocontrol	Manipulate Strains	Test in Vitro	Greenhouse Test	Field Test	Field Test
2.9 Bacterial Biocontrol	Manipulate Strains	Test in Vitro	Greenhouse Test	Field Test	Field Test

Nematodes on Potatoes

	Year 1	Year 2	Year 3	Year 4	Year 5
<u>Lead Array</u>					
3.1 Develop Cultivars	Establish Plots	Field Test	Field Test	Field Test	Release New Cultivars
3.2 Biocontrol	Conduct Surveys	Isolate Organisms	Greenhouse Test Organisms	Field Test	Field Test
<u>Safeguard Array</u>					
3.3 Identify Biocontrol	Test in Vitro	Test in Greenhouse	Field Test	Field Test	Release
<u>Optimizing Array</u>					
3.4 Molecular Techniques	Gel Electrophoresis	Identify RLFP	Make Probes	Identify Genes	Isolate Genes
<u>Supplementary Array</u>					
3.5 Identify Genes	Use Molecular Techniques	Identify Genes	Isolate Genes	Insert Genes	Test Product
3.6 Fungal Biocontrol Agents	Manipulate Strains	Test in Vitro	Greenhouse Test	Field Test	Field Test
3.7 Bacterial Biocontrol Agents	Manipulate Strains	Test in Vitro	Greenhouse Test	Field Test	Field Test

Safeguard Array:

3.3 Begin exploration for naturally occurring fungal and bacterial biocontrol agents.

Optimizing Array:

3.4 Identify fungal and bacterial biocontrol agents for abilities to reduce pest populations.

Supplementary Array:

3.5 Identify genes for resistance in potato and incorporate into other potato cultivars.

3.6 Genetically manipulate identified fungal biocontrol strains for temperature tolerance, competitiveness, pesticide tolerance.

3.7 Genetically manipulate identified bacterial biocontrol agents for host range increase, virulence, and survivability.

PLANT PATHOGEN IMPLEMENTATION

Biological Control Implementation Phase 1: Biocontrol in Limited Areas

The major objective of the biological control program will be operational in Beltsville, MD, Wisconsin, Oregon, and Idaho. Beltsville will provide leadership in preparation of delivery systems of microbial control agents which will be tested with and without broad spectrum fungicides and fumigants. Beltsville has already developed the capabilities for liquid fermentation and for limited production of biocontrol formulations to be tested.

Phase 2 - Biocontrol in Additional Areas

After 3 years of research in Phase 1, research will be expanded to include California, Minnesota, Ohio, Florida, Texas, and Michigan. The arrays of research will be identical, except that there will be more knowledge and expertise accumulated during the first 3 years which will facilitate and expedite research in the expanded areas.

Lead Array

1.1 Using selective culture media, isolate and identify new microorganisms (fungi, bacteria, actinomycetes) antagonistic against the major potato soilborne pathogens.

1.2. Screen new microorganisms and existing strains in the genera *Gliocladium spp.*, *Trichoderma spp.*, *Laetisaria spp.*, *Talaromyces spp.* , and *Verticillium spp.* against the major pathogens.

1.3. Improve delivery systems of potential biocontrol microorganisms, especially the system of applying the beneficial microorganisms on potato seed pieces.

Safeguard Array

1.4. Study the degree of control of major potato soilborne diseases with strains of beneficial microorganisms that have already shown promise in the field in Wisconsin, Idaho, and Oregon during the first 3 years and expand this effort to other states during the last 2 years.

1.5. Study the degree of control of major soilborne potato diseases with organic amendments and crop rotation used alone or in combination with biocontrol agents.

Optimizing Array

1.6 Study the compatibility of potential biocontrol agents with potato seed piece pesticides that are used commercially in small amounts to control potato diseases in the field.

1.7 Combine potential biocontrol agents with reduced amounts of broad spectrum fumigants used on potatoes.

Supplementary Array

1.8. Develop bioengineered strains of *Gliocladium spp., Trichoderma spp., Talaromyces spp., V. trichorpus*, and *Laetisaria spp.* that will embody desirable qualities, i.e. efficacy, persistence, tolerance to pesticides, long shelf life, and non-toxicity to other organisms.

1.9. Unravel the mechanism of action of promising biocontrol microorganisms against *Verticillium dahliae* and *Rhizoctonia solani*, two very important soilborne pathogens.

1.10. Study survival and proliferation (systems ecology) of the most promising biocontrol agents in soil and in potato rhizosphere.

Biological Control Implementation Phase 2: The proposed major objectives of the biological control program will be done in one phase and will be operational in Beltsville, MD, Salisbury, MD, Rio Grande Valley in Texas, and Centerton, NJ. Beltsville will provide the leadership in fundamental research and in the preparation of delivery systems for microbial biocontrol agents that will be tested with and without broad spectrum fungicides and fumigants. Beltsville has already developed the capabilities for fermentation and for production of experimental quantities of biocontrol formulations.

USDA Ground Water Quality - ARS Biological Control Action Plan

Lead Array

1.1. Isolate and identify new soil fungi and bacteria antagonistic against:

Rhizoctonia on cucumbers and lettuce	Beltsville
Fusarium on melons	Beltsville & Salisbury, MD
Verticillium on eggplants	Centerton, NJ

1.2. Screen new microorganisms and existing strains in the genera *Gliocladium spp.*, *Trichoderma spp.*, *Laetisaria spp.*, and *Talaromyces spp.* against:

Rhizoctonia on cucumber and lettuce
Fusarium wilt on melons and cantaloupes
Verticillium wilt on eggplants
Sclerotinia drop on lettuce and tomato
White rot on onion

1.3 Improve delivery systems of potential biocontrol microorganisms

Safeguard Array

1.4 Study the degree of control of major diseases of specialty vegetables with strains of beneficial microorganisms that have already shown promise in the field:

Sporidesmium spp. on *Sclerotinia spp.* and *Sclerotium spp.*
Gliocladium spp. on *Rhizoctonia spp.* and *Fusarium spp.*
Talaromyces spp. on *Verticillium spp.*

Optimizing Array

1.5 Study the compatibility of potential biocontrol agents with broad spectrum fungicides and fumigants.

1.6 Introduce potential biocontrol agents after soil treatment with reduced amounts of pesticides and study establishment and proliferation of biocontrol agents in soil.

Supplementary Array

1.7 Develop bioengineered strains of biocontrol agents that will embody desirable characteristics for biological control.

1.8 Unravel the mechanisms of action of promising biocontrol microorganisms against the major pathogens of specialty vegetables.

1.9 Study systems ecology of biocontrol agents in soil and in plant rhizosphere.

Seedling Diseases of Cotton

Lead Array

1.1 Test the *Gliocladium virens* strain collection for those isolates showing the most extensive and/or broad spectrum activity against members of the seedling disease complex (*Rhizoctonia, Pythium*).

1.2 Field test candidate strains for efficacy in disease control and determine effective treatment application levels.

Safeguard Array

1.3 Determine the effectiveness of biocontrol agents in combination with reduced levels of fungicide treatment.

1.4 Assess any adverse effects on crop, livestock, or other beneficials that might result from treatment with the biocontrol agent.

Optimizing Array

1.5 Develop growth, formulation, and application techniques to optimize the activities of the biocontrol agent.

1.6 Study the effects of the application of biocontrol strains in combination.

Supplemental Array

1.7 Carry out substrate studies to determine the effects of substrate formulations on the production of secondary metabolites by the biocontrol strains.

1.8 Employ biotechnology to detect and isolate genes governing the mechanisms observed in the biocontrol process. Learn to manipulate these genes so that they may be transferred and combined with genes coding for other favorable characters or separated from unfavorable ones to produce improved biocontrol agents.

I. Soilborne Diseases of Potatoes

	Year 1	Year 2	Year 3	Year 4	Year 5
Lead Array					
1.1 Isolate and identify new potential biocontrol agents	Isolate new agents, Beltsville,ID,WI,OR	—	—	—	—
Screen new microorganisms	Screen in MD, ID, WI, OR	Screen in MD, ID, WI, OR	—	—	—
Improve delivery systems	Improve system-Beltsville	—	—	—	—
Safeguard Array					
1.4 Study control in the field with biocontrol agents	Study control in MD, ID, WI, OR	Study control in MD, ID, WI, IR	Study control in MD, ID, WI, OR	Study control in 10 states	Study control in 10 states
Study control with crop rotation and organic amendments	Crop management in ID and OR	Crop management in ID and OR	Crop management in ID and OR	Crop management in OD, OR, WI, OH, MI	Crop management in ID, OR, WI, OH, MI
Optimizing Array					
1.6 Compatibility of biocontrol agents with fungicides and fumigants	Compatibility study in greenhouse and lab, Beltsville	Compatibility study in greenhouse and lab, Beltsville, ID	—	—	—
Combine biocontrol agents with reduced amounts of pesticides	Combine biocontrol agents with pesticides in the field	Combine biocontrol agents with pesticides in the field	Combine biocontrol agents with pesticides in the field	Combine biocontrol agents with pesticides in the field	Combine biocontrol agents with pesticides in the field
Supplementary Array					
1.8 Develop bioengineered strains, unravel mechanisms, and study systems ecology	Study mechanisms and systems ecology	Develop new strains, study mechanisms, study ecology	Develop new strains, study mechanisms, study ecology	Develop new strains, study mechanisms, study ecology	Develop new strains

II. Soilborne Diseases of Specialty Vegetables

	Year 1	Year 2	Year 3	Year 4	Year 5
Lead Array					
1.1 Isolate new potential bio-control agents	Isolate new agents, Beltsville, MD	—	—	—	—
Screen new microorganisms	Screen in MD, NJ and TX	Screen in MD, NJ and TX	—	—	—
Improve delivery systems	Improve systems, Beltsville	Improve systems, Beltsville	—	—	—
Safeguard Array					
1.4 Study control in the field	Control in the field in all locations	Control in the field in all locations	Control in the field in all locations	Control in the field in all locations	Control in the field in all locations
Optimizing Array					
1.5 Compatibility of biocontrol agents with fungicides and fumigants	Compatibility study in the greenhouse and lab, Beltsville	Compatibility study in the greenhouse and lab, Beltsville	—	—	—
Combine bio-control agents with reduced amounts of pesticides	Combine bio-control agents with pesticides in the field	Combine bio-control agents with pesticides in the field	Combine bio-control agents with pesticides in the field	Combine bio-control agents with pesticides in the field	Combine bio-control agents with pesticides in the field
Supplementary Array					
1.7 Unravel mechanism, develop bio-engineered strains and study systems ecology	Study mechanisms & system ecology	Study mechanisms & systems ecology and develop new strains	Study mechanisms & systems ecology and develop new strains	Study mechanisms & systems ecology and develop new strains	Study mechanisms & systems ecology ecology and develop new strains

III. Seedling Diseases of Cotton

	Year 1	Year 2	Year 3	Year 4	Year 5
Lead Array					
1.1 & 1.2 Test *G. virens* strains for disease control	Test old strains for activity	Test new strains for activity Develop screening methods	Field test strains for disease control efficacy	Determine minimal effective treat-levels	Field test biocontrol strains in wide areas
Safeguard Array					
1.3 & 1.4 Test agent efficacy with reduced fungicides	Assay biocontrol strains against fungicides	Assay strains for phytotoxicity	Assay strains for adverse effect on animals	Assay strains for adverse effect on beneficials	Test strains for efficacy with reduced fungicides treatments
Optimizing Array					
1.5 & 1.6 Develop formulation and application techniques	Test effect of formulation on disease control	Determine optimum form and concentration of biocontrol inoculum	Develop optimum application technique for biocontrol agent	Use biocontrol strains in combinations	Optimize strain area combinations
Supplemental Array					
Carry out biochemical, ecological and genetic studies on biocontrol agents	Study effect of substrate on secondary metabolite production	Study the mechanisms involved in biocontrol	Study the ecology of biocontrol agents	Employ biotechnology to isolate, transfer and study genes associated with biocontrol mechanisms	Field test genetically altered biocontrol agents

WEED IMPLEMENTATION PLANS

1. Cocklebur

Cocklebur:

Herbicide usage (atrazine/alachlor): #1 Acres treated (millions): corn = 24.9, soybeans = 31.7, rice = 5.2, Total = 62.3

Crop loss caused: US = #4 US: (soybeans = #1, cotton = #2, peanuts = #3, grain sorghum = #5, South = #1 (soybeans 120.4, corn = 9.2, cotton = 5.0, tobacco = 9, peanuts = 3.6, sorghum = 1.3, Total 144)

Biocontrol agents known:

Indigenous: 1) *Alternaria helianthi*

Foreign: 2) *Emphytoecia versicolor* - Argentina (cerambycid stem borer) host-range testing completed, looks host specific; reduces plant size and seed production by 40%.

3) Tephretid and mordellid seed feeders (Argentina) not tested. Exploration needed: Argentina, India-Pakistan

Conflicts of interest: none

1) Sunflower closely related
2) Wildlife usage: 3*, 2 user species

Site of origin/native distribution: South America, North America

Weedy species - 1 introduced, 1 native
Total US species - 1 introduced, 1 native

Midwestern Weeds
Cocklebur (*Xanthium strumarium*)

Lead Array

1. Conduct quarantine testing and release the stem boring cerambycid beetle *Emphytoecia versicolor*, from Argentina.

2. Conduct host-range testing on other known insect pests.

3. Develop *Alternaria helianthi* as a biocontrol agent.

4. Explore for additional natural enemies (indigenous and foreign pathogens and foreign insects).

5. Conduct host-range testing of the tephritid and mordellid seed feeders in Argentina.

2. Velvetleaf

Herbicide usage: (atrazine/alachlor): #3
Acres treated (millions): corn = 23.5, soybean = 14.8, Total = 38.3

Crop losses caused: US = #6
US: (Soybeans = #6)
South: #41 (soybeans = 5.4, cotton = 3.0, Total = 8)

Biocontrol agents known:
Indigenous : 1) fungus - *Colletotrichum coccodes*;
2) fungus - *Fusarium lateritium*.
3) *Nisethrea louisianica* (rhopalid seed feeder)

Foreign: two spp. seed feeders - Argentina: host-range testing nearly complete, appear specific

Explorations needed: N. Amer., China

Conflicts of interest: very little, weed is in same family with cotton and okra.

Site of origin/natural distribution: China?, Tropical and Southern Temperate America, Asia. Total species in US - 1 introduced, 21 native. Weed species - introduced.

Midwestern Weeds
Velvetleaf (*Abutilon theophrasti*)

Lead Array

1. Conduct taxonomic studies to determine the site of origin of velvetleaf and of the genus *Abutilon*.

2. Introduce into quarantine and test the two species of insect seed feeders under study in Argentina.

3. Explore for natural enemies of velvetleaf and other closely related species of the genus in China and South America.

4. Search for additional indigenous pathogens that could be used as biocontrol agents.

5. Develop the two fungi, *Colletotrichum coccodes* from Vermont and Canada, and *Fusarium lateritium* from Mississippi as biocontrol agents.

3. Bindweed

Herbicide usage: (atrazine/alachlor): #5 Acres treated (millions): soybeans = 9.6, cotton = 4.5, corn = 3.3, rice = 0.6, Total = 18.0

Crop losses caused: US = #15
US: (wheat = #7, other small grains = #6); South: #36 (cotton = 10.4, sorghum = 3.4, Total = 14).

Biocontrol agents known:
1) *Tyta luctuosa* (Noctuid moth) - released in TX and OK 1987
2) *Aceria convolvuli* (mite) - released in TX 1989
3) *Noctuelia floralis* (noctuid moth) - Greece-tested
4) *Spermophagous sericeus* - bruchid seed beetle, Greece - tested
5) *Erysiphe convolvuli* (rust) Greece

Conflicts of interest: very little
1) Feeds on native plant genus *Colystegia* in west coast states.
2) Sweet potato closely related.
3) 13 ornamental species.

Site of origin and natural distribution: Eurasia
Weed species - 1 introduced
Total US species - 1 introduced, 5 native

Field bindweed (*Convolvulus arvensis*)

Lead Array

1. Obtain establishment and dispersal of the noctuid moth, *Tyta luctuosa*, already released in Texas and Oklahoma in 1987.

2. Obtain establishment and dispersal of the mite *Aceria convolvuli*, released in Texas in 1989.

3. Test and obtain permits for release of other known European control agents, such as the pyralid moth *Noctuelia floralis* and the bruchid *Spermophagous sericeus*.

4. Test and obtain permission to release the Eurpean powdery mildew *Erysiphe convolvuli*.

4. Nutsedge

Herbicide usage: (atrazine/alachlor): #16
Acres treated (millions): Corn = 1.7, cotton = 0.8, soybean = 0.4, rice = 0.4, Total = 3.3.

Crop losses caused: US = #9
US: (peanuts = 1, cotton = 3, corn = 3, soybeans = 7)South: #6 (cotton = 30.7, soybeans = 14.7, corn = 8.8, peanuts = 5.7, rice = 5.4, tobacco = 2.7, sorghum = 0.3, Total = 68)

Biocontrol agents known:
Indigenous: 1) *Puccinia canaliculata* (rust) - field tests at Tifton, GA gave good control of yellow nutsedge. Foreign: 2) 30 spp. stenophagous insects in India, Pakistan, and Philippines - need testing 3) *Stenophorus sp* (weevil) - feeds in tubers - Argentina. 4) Three species fungi found on purple nutsedge in Israel - all need testing.

Conflicts of interest: Yellow nutsedge - tubers minor wildlife food Purple nutsedge - none Wildlife usage: 23*, 23 user species

Site of origin and natural distribution:
Pan-tropical, warm temperateWeedy species: 1 introduced, 1 nativeTotal US species: 10 introduced, 83 native

Nutsedges (*Cyperus rotundus* and *C. esculentus*)

Lead Array

1. Develop the indigenous rust pathogen, *Puccinia canaliculata*, for control of yellow nutsedge.

2. Introduce, test and develop the three pathogens from Israel recently found attacking purple nutsedge.

3. Test the host range and biocontrol potential of the 30 species of stenophagous insects from the Philippines that attack nutsedge.

4. Test the host range of the Argentine weevil, *Stenophorus sp.* that feeds in the rhizome and tubers.

5. Conduct explorations for indigenous and foreign biocontrol agents.

5. Johnsongrass

Herbicide usage: (atrazine/alachlor): #9 Acres treated (millions): corn = 2.1, soybean = 2.9, cotton = 3.8, Total = 8.8

Crop losses caused: US = #5 US: (cotton = 1, grain sorghum = 2, sugarcane = 3, soybeans = 5, corn = 7) South: #1 (soybeans = 110.2, cotton = 37.8, corn = 32.9, grain sorghum = 12.7, sugarcane = 6.5, Total = 200)

Biocontrol agents known:

Indigenous: 1) *Bipolaris sorgicola* (fungus) - excellent control in prelim. field test but since inconsistent in NC.

2) *B. halepense* (fungus) - not completely specific- NC

3) *Sphacelotheca holci* - field testing in LA, CA

4) *Fusarium sp.* - MS

Foreign: 5) *Metacrambus carectellus* (moth) - feeds only in rhizomes in field in Israel but feeds slightly on sorghum in lab tests. Needs testing in field,preferably on an isolated island.

Explorations needed: Area of natural distribution, especially Sudan.

Conflicts of Interest:

1) Minor usage for forage, hay and wildlife food
2) Very closely related to cultivated sorghums

Site of origin and natural distribution:

Sudan(?), N. Africa, SW Asia
Weedy species: 1 intro, none native
Total US species: 5 intro, none native

Midwestern Weeds
Johnsongrass (*Sorghum halepense*)

Lead Array:

1. Develop indigenous pathogens as biocontrol agents; *Bipolaris sorgicola*, *B. halepense*, *Sphacelotheca holci*, and *Fusarium sp.*

2. Field test the noctuid moth, *Metacrambus carectellus*, from Israel to measure host range, preferably on an isolated island.

3. Explore for foreign insects and pathogens as biocontrol agents in the area of natural distribution, especially in the Sudan.

4. Explore for additional indigenous biocontrol agents in North America.

6. Ragweeds

Herbicide usage: (atrazine/alachlor)
Acres treated (millions); corn = 6.9, soybean = 6.5, Total = 13.4

Crop losses caused: US = #16
US: (no data) South: #12 (soybean = 19.5, tobacco = 3.8, corn = 3.8, peanuts = 1.0, pasture and hay = 20.7, Total = 49)

Biocontrol agents known:
Indigenous: 1) *Puccinia xanthii*
Foreign: None
Exploration needed: US for pathogens, Argentina for insects and pathogens

Conflicts of interest: Severe - sixth most important food for wildlife (excluding crops) in US Wildlife usage: 164*, 71 user species

Site of origin/natural distribution: N. Amer, S. Amer
North American, South America
Weedy species: 10 native, none introduced
Total US species: 25 native, none introduced

Ragweed (*Ambrosia spp.*)

Lead Array

1. Survey for and develop promising indigenous plant pathogens as biocontrol agents.

7. Pigweeds

Herbicide usage: #4
Acres treated (millions): corn = 12.1, soybean = 12.0, cotton = 2.3, Total = 26.4

Crop losses caused: US = #1
US: corn = 1, grain sorghum = 1, sugarbeet = 1, soybean = 3, other grain = 4, peanuts = 5, cotton = 7
South: #13 (soybean = 37.1, corn = 3.4, pasture and hay = 3.1, sorghum = 2.0, cotton = 1.4, tobacco = 0.8, peanuts = 0.7, Total = 49)

Biocontrol agents known:
Indigenous: none
Foreign: 1) *Hypolixus truncatulus* (weevil) - Pakistan, attacks only species of *Amaranthus*
2) Flea beetles, 2 *Disonycha*, 1 *Phenrica*, plus corimelaenid bugs - South American - commonly killed plants
Explorations needed: South America

Conflicts of interest: Severe
1) Ninth most important plant in US for wildlife food.
Wildlife users: 114*, 55 user species
2) Grain amaranth (*A. cruentus*) is potential cereal grain crop.
3) Widely used ornamental

Site of origin and natural distribution: N. America, S. America
Tropical, Temperate zones of the world
Weedy species: 5 introduced, 11 native
Total US species: 9 introduced, 28 native

8. Foxtail

Herbicide usage: #2
Acres treated (million): corn = 43.2, soybean = 12.5, Total = 55.7

Crop losses caused: US = #2
US: soybean = 2, corn = 3, sugarbeet = 3, grain sorghum = 4
South: (not a pest)

Biocontrol agents known:
Indigenous: None
Foreign: None
Exploration needed: US and overseas for pathogens

Conflicts of interest: Severe
1) Important wildlife food - 226*, 77 user species
2) Closely related to forage and pasture grasses
3) Millet closely related

Site of Origins and Natural distribution:
Europe, tropical areas
Weedy species: 7 introduced, 2 native
Total US species: 14 introduced, 16 native

Midwest Weeds
Foxtail (*Setaria sp.*)

Lead Array

1. Survey to find plant pathogens for use as control agents.

2. Develop broad-spectrum pathogens through directed mutagenesis.

3. Develop herbicide application methods to reduce usage and to exclude crop damage.

4. Develop crop/herbicide rotation systems that would allow for use of low rates of diphenylether herbicides post emergence over the top to control the foxtails.

9. Quackgrass

Herbicide usage: #10
Acres treated (millions) : corn = 7.8, Total = 7.8

Crop losses caused: US = #14
US: corn = #6
South: very minor pest

Biocontrol agents known:
Indigenous: None
Foreign: None
Exploration needed:

Conflicts of Interest: minor
1) wildlife: 21*, 16 user species
2) hay - minor usage

Site of origin and natural distribution: Eurasia
Weedy species: introduced
Total US species: 12 introduced, 20 native

Quackgrass (*Agropyron repens*)

Lead Array

1. Search for and develop indigenous plant pathogens as biocontrol agents.

2. Explore for control agents in Eurasia.

10. Morning glories

Herbicide usage: (not listed)

Crop losses caused: US = #8
US: Soybeans = #4, cotton = #4, sugarbeet = #4, grain sorghum = #6, peanuts = #7
South: #2 (soybean = 120.5, corn = 15.8, cotton = 12.4, tobacco = 6.?, peanuts = 4.8, sorghum = 2.8, rice = 2.4, sugarcane = 2.? Total = 174)

Biocontrol agents known:
Indigenous: 1) *Colletotrichum dematium*
Foreign: 2) *Botanochara impressa* (leaf beetle) - Brazil, research by Brazilian workers
Explorations needed: Southern Brazil, Paraguay, Uruguay, Argentina

Conflicts of interest:
1) Minor use for ornaments - 21 species used. Very minor wildlife food - 5*, 9 useful species.
2) Sweetpotato very closely related

Site of origin and natural distribution: Tropical America
Weedy species - 6 introduced, 15 native
Total US species - 12 introduced, 30 native

Morning glories (*Ipomoea spp.*)

Lead Array

1. Search for and develop indigenous plant pathogens as biocontrol agents.

2. Explore for control agents in southern South America (Argentina, Uruguay, Paraguay, Brazil)

3. Cooperate with Brazilian entomologists at Compinas who are developing biocontrol of morning glories.

11. Crabgrass

Herbicide usage: #14
Acres treated (millions): corn = 3.2, cotton = 1.7, rice = 0.3, Total = 5.2

Crop losses caused: US = #3
US: corn = #2, peanuts = #2, sugarcane = #2, grain sorghum = #3, cotton = #6
South: #29 (corn = 5.8, sugarcane = 6.5, soybeans = 1.5, tobacco = 1.2, peanuts = 1.0, grain sorghum = 0.8, Total = 17)

Biocontrol Agents Known:
Indigenous: *Ustilago syntherismae* (smut pathogen)
Tilletia pulsherrima (smut pathogen)
Foreign: None

Exploration needed: US and worldwide (esp. Africa?) for pathogens

<u>Conflicts of interest:</u> minor
Minor value for grazing. Wildlife - 55[*], 22 user species

<u>Site of origin/native distribution:</u> origin unknown, now cosmopolitan.
Weedy species: 4 introduced, 4 native
Total US species: 7 introduced, 17 native

Crabgrass (*Digitaria spp.*)

Lead Array

1. Search for and develop indigenous and foreign plant pathogens as biocontrol agents.

2. Continue development of the indigenous smut pathogens *Ustilago syntherismae* and *Tilletia pulcherrima*.

12. <u>Leafy spurge</u>

<u>Herbicide usage:</u> ?
Area treated: ?

<u>Crop Losses Caused:</u> US = ?

<u>Biocontrol agents known:</u>
Indigenous: 1) *Alternaria tenuissima*
2) *Uromyces heliotropii*, *U. sp*
Foreign: Several insects studied intensively, active program of introduction in Canada/Montana/North Dakota, several insects recently approved for release, a few recently released.

<u>Conflicts of interest:</u> minor
1) Some non-target feeding by BC agents on native, closely related, non-weedy spurges.
2) Some ornamentals closely related, especially poinsettia.
3) Very large genus, many native species.

Leafy Spurge (*Euphorbia esula*)

Lead Array

1. Continue development and dispersal of insects already released.

2. Continue host-range testing and obtain permits to release the insects.

3. Continue explorations in China and Europe for additional biocontrol agents.

13. Smartweed

Herbicide usage: #7 Acres treated (millions): corn = 5.7, soybeans = 4.9 Total = 10.6

Crop losses caused: US = #11
South: #32 (Soybeans = 13.4, rice = 1.4, Total 15)

Biocontrol agents known:
Indigenous - none
Foreign - none
Exploration needed:

Conflicts of interest: moderate to severe
1) Wildlife food - 128*, 66 user species

Site of origin/natural distribution:
Temperate zones of the world. In US
Weedy species: 13 native, 7 introduced
Total species: 69 native, 14 introduced

Smartweed (*Polygonum spp.*)

Lead Array

1. Search for and develop indigenous plant pathogens for use as biocontrol agents.

2. Explore for natural enemies (insects and plant pathogens) in temperate areas of the world.

14. Lambsquarters

Herbicide usage: #8 Acres treated (millions): corn = 6.0, soybean = 4.9, Total = 10.2

Crop losses caused: US = #10
US: sugarbeet = #2, other small grains = #5
South: very minor pest

Biocontrol agents known:
Indigenous: 1) *Ascochyta caulina*
2) *Cercospora chenopodii*
Foreign: None
Exploration needed:

Conflicts of interest: minor
1) Weed occasionally used as a vegetable
2) Wildlife - 61*, 40 user species

Site of origin and natural distributions:
Temperate areas of the world
Weedy species - 8 introduced, 9 native
Total US species - 15 introduced, 29 native

Lambsquarter (*Chenopodium spp.*)

Lead Array

1. Test and develop the indigenous plant pathogens *Ascochyta caulina* and *Cercospora chenopodii* as biocontrol agents.

2. Search for indigenous plant pathogens as biocontrol agents.

3. Explore in Europe for plant pathogens and insects for use as biocontrol agents.

15. Thistle

Herbicide usage: #11
Acres treated (millions): corn = 4.7, soybeans = 1.8, Total = 6.5

Crop losses caused: US = #17
South: #15 (pasture and hay = 34.5, Total = 34.5

Biocontrol agents known:
Indigenous: some fungi
Foreign: 1) *Rhinocyllus conicus* (weevil) - Europe, released in US, excellent control in MT, VA, MO
2) *Trichosirocallus horridus* (weevil) - Europe, released and some control in VA.
3) *Puccinia carduorum* (rust) - European, released in VA.

Conflicts of interest: very little

Site of origin and natural distribution: Eurasia
Thistles are in 96 genera: *Carduus, Cirsium, Centaurea, Onopordum, Sonchus, Silybum*, and *Acroptilon.*
Introduced: 6 sp. *Carduns*, 1 sp *Onodopordon*, 1 sp *Silybum*, 3 spp. *Cirsium*, some *Centaurea*

Native: 42 spp. *Cirsium*, -- spp. *Centaurea*

Thistles *Carduus, Cirsium, Centaurea, Silybum, Onopordum. Sonchus, Acroptilon*

Lead Array

1. Continue dispersal and evaluation of control achieved with the weevils already released, *Rhinocyllus conicus* and *Trichoserocallus horridus*, and of the rust, *Puccinia carduorum.*

16. Hemp Sesbania

Herbicide usage: not listed

Crop losses caused: US: rice = #3
South: #11 (Soybeans = 46.3, rice = 3.8, Total 50

Biocontrol agents known:
Indigenous : *Colletotrichum truncatum* (MS)
Foreign: *Diplogrammus quadrivittatus* (stem borer), *Eudiagogus episcopalis* (root feeder), *Rhyossomatus marginatus* (seed feeder), and *Apion sp.* (flower feeder) (all weevils) and a cottony-cushion scale in Argentina and Bolivia heavily damage and commonly kill the weed; introduced into South Africa in 1982 for biocontrol.

Site of origin and natural distribution:
Tropical and subtropical area
Weedy species: 2 introduced, 3 native
Total US species: 2 introduced, 5 native.

Hemp sesbania (*Sesbania exaltata*)

Lead Array

1. Conduct host-range and biological testing of the weevils *Diplogrammus quadrivettatus*, *Eudiagogus episcopalis*, *Rhyossomatus marginalis*, and *Apion sp.* at the Hurlinghams, Argentina laboratory.

2. Introduce any of the above approved 4 weevils into quarantine in the US for testing and field release.

3. Develop *Colletotrichum truncatum* and search for and develop additional indigenous plant pathogens in the US that could be used for biocontrol agents.

ARTHROPOD PEST IMPLEMENTATION PLANS

Corn Rootworm Complex
Lead Array

1.1.1.1 Evaluate tillage and crop rotational systems that are acceptable to corn producers and will reduce CRW populations.

Year 1. Establish research plots for evaluating tillage and rotational systems that are economically and socially viable; emphasis on areas with high risk for ground water contamination.

Year 2. Evaluate influence of tillage and rotational systems on population levels of species in the CRW complex; emphasis on northern corn rootworm.

Year 3. Continue evaluation per year 2.

Year 4. Continue evaluation per years 2 and 3.

Year 5. Continue evaluation per years 2, 3 and 4; compile and analyze data, including economic assessment.

1.1.1.2 Reduce adult CRW populations by semiochemically-based methods.

Year 1. Develop and evaluate formulations and application technology for particulate and sprayable baits; estimate impact on non-target species and evaluate potential as delivery systems for biological agents.

Year 2. Evaluate performance of "best" formulations in production-scale field trials.

Year 3. Evaluate performance in regional field trials; emphasis on defining the size of the control area.

Year 4. Continue per year 3.

Year 5. Evaluate full scale control approach; emphasis on areas with high risk for ground water contamination.

1.1.1.3 Reduce CRW larval populations with insect-parasitic nematodes.

Year 1. Identify nematode species and strains that are pathogenic for CRW larvae and ecologically adaptable to the corn-soil habitat.

Year 2. Continue to identify nematode species and strains that are pathogenic for CRW larvae and ecologically adaptable to the corn-soil habitat; emphasis on ecological adaptation.

Year 3. Develop formulation and application technologies and test performance in controlled environments.

Year 4. Evaluate control potential of selected species in field trials; emphasis on root protection and pest population reduction.

Year 5. Continue field evaluations and optimize performance.

1.1.1.4 Develop improved population monitoring systems to optimize control decisions.

Year 1. Develop monitoring systems; emphasis on preovipositinal adults and 1st stage larvae.

Year 2. Per year 1.

Year 3. Determine relationships and efficiency of sampling methods to the "true" population structure (density and developmental) and integrate relationships of pest population structure and density with economic damage thresholds via modeling.

Year 4. Continue per year 3.

Year 5. Transfer monitoring systems and decision models to Cooperative Extension Service.

Safeguard Array

1.1.1.5 Investigate potential of *Beauveria spp.* and other pathogens for control of CRW larvae in soil.

Year 1. Evaluate *Beauveria spp.* strains for virulence to immatures and adults.

Year 2. Develop delivery systems and evaluate interactions of *Beauveria spp.* with host stages and with potential soil biological and physical synergists and antagonists.

Year 3. Continue per year 2; emphasis on antagonists and synergists.

Year 4. Perform field tests with selected strains.

Year 5. Continue field testing and optimize performance.

Optimizing Array

1.1.1.6 Explore for additional natural enemies in foreign and indigenous CRW populations.

Year 1. Survey *Diabrotica spp.* populations along the southern range of the U.S. distribution and in areas of Mexico and South America, especially Argentina, Brazil and Peru.

Year 2. Continue survey per year 1; identify potential biological control agents, and introduce exotic species into quarantine.

Year 3. Continue per years 1 and 2; increase data collection on factors affecting host-natural enemy interactions.

Year 4. Continue per years 1, 2 and 3; initiate analysis of relationships between pathogen and parasitoid incidence and pest densities; field release promising exotic natural enemies.

Year 5. Continue per previous years; evaluate release sites for establishment of exotic natural enemies; summarize survey and data on host-natural enemy relationships.

Supplemental Array

1.1.1.7 Develop a strain of *Bacillus thuringiensis* (*B. t.*) that will be effective against the CRW species.

Year 1. Evaluate existing isolates for pathogenicity to CRW adults and larvae.

Year 2. Continue per year 1; contrast efficacy of virulent strains.

Year 3. Continue per years 1 and 2; develop formulations and delivery systems; evaluate control performance in controlled environments.

Year 4. Field test.

Year 5. Continue field test.

European Corn Borer Implementation Plan

Lead Array

1.1.2.1 Develop effective delivery systems to increase the efficacy of commercial B. t. preparations.

Year 1. Identify UV screens and feeding stimulants, incorporate into starch matrix granules, and assay effectiveness.

Year 2. Evaluate on corn under controlled conditions.

Year 3. Small scale field studies.

Year 4. Pilot plant production.

Year 5. Evaluate efficacy of aerial applications.

1.1.2.2 Reintroduce *Lydella thompsoni* and evaluate its efficacy relative to currently used corn hybrids and cultivation practices.

Year 1. Facilitate development of mass rearing techniques; designate release sites.

Year 2. Survey for possible alternate hosts; initiate research on plant cultivar/kairomone relationships.

Year 3. Evaluate releases in field cages; investigate compatibility with indigenous pathogens.

Year 4. Evaluate releases in diversified cropping areas.

Year 5. Evaluate releases and establishment in "typical" Corn Belt corn agorecosystems.

1.1.2.3 Evaluate integrated control using *Macrocentrus grandii* and *Nosema spp.*

Year 1. Investigate influence of *N. pyrausta* on *M. grandii* behavior; determine methods of transmission of *N. pyrausta* by *M. grandii*, e.g. mechanical vectoring, transovarial, etc.

Year 2. Facilitate mass rearing techniques.

Year 3. Conduct functional response studies in laboratory and field cages.

Year 4. Evaluate effectiveness of *M. grandii* in *N. pyrausta*-infected ECB

populations.

Year 5. Model the above relationships.

1.1.2.4 Develop improved population monitoring systems (using pheromones and other techniques) to optimize control decisions.

Year 1. Conduct laboratory research on biological activity of blends of sex pheromones.

Year 2. Evaluate, in laboratory, pheromones that will be competitive with "calling" females in attracting male moths.

Year 3. Conduct field tests.

Year 4. Model relationships between adult catches and larval populations.

Year 5. Continue large scale evaluation of monitoring-timing techniques.

Safeguard Array

1.1.2.5 Evaluate indigenous and introduced *Trichogramma spp.* and other egg parasitoids.

Year 1. Select promising species. Arrange for acquisition and/or introduction; concentrate on *T. maidis*, *T. nubilale* and *T. ostriniae*. Evaluate other *Trichogramma spp.* on basis of economics of rearing. Arrange for introduction of Asian scelionids.

Year 2. Conduct laboratory research on effectiveness of parasitoids; select most promising species.

Year 3. Conduct small field plot studies. Investigate compatibility of *Trichogramma spp.* with *N. pyrausta*-infected ECB eggs.

Year 4. Develop mass release and evaluation techniques for large field tests.

Year 5. Evaluate effectiveness.

1.1.2.6 Evaluate the potential of *Beauveria bassiana* and other pathogens for control of ECB larvae.

Year 1. Conduct laboratory assays on isolates of *B. bassiana*, a nuclear polyhedrosis virus of celery looper, *Nosema furnacalis*, and *Nosema sp. nov.* isolated from ECB.

Year 2. Facilitate production of pathogens.

Year 3. Conduct laboratory studies on effectiveness of combinations of pathogens.

Year 4. Conduct field studies.

Year 5. Continue field studies.

Optimizing Array

1.1.2.7 Maximize the use of currently existing and newly developed resistant corn cultivars.

Year 1. Identify existing resistant germplasm.

Year 2. Incorporate germplasm into corn breeding program.

Year 3. Evaluate resistant germplasm in small field plots.

Year 4. Evaluate resistant germplasm for effectiveness on larger scale.

Year 5. Continue per year 4.

1.1.2.8 Conduct foreign exploration for additional natural enemies.

Year 1. Identify possible natural enemies.

Year 2. Evaluate natural enemies in laboratory.

Year 3. Facilitate production and release protocols.

Year 4. Conduct field cage studies.

Year 5. Conduct large scale field studies.

Supplemental Array

1.1.2.9 Investigate mechanism of the colonization of corn by *Beauveria bassiana*.

Year 1. Conduct laboratory studies on introducing inoculum.

Year 2. Conduct inoculum studies under field conditions.

Year 3. Facilitate production and release protocols.

Year 4. Conduct field cage studies.

Year 5. Conduct large scale field studies.

1.1.2.10 Investigate means to avoid development of resistance in ECB populations to B. t. toxins produced by transgenic plants.

Year 1. Determine potential of ECB to develop resistance to B. t.

Year 2. Determine potential for cross-resistance to other subspecies of B. t.

Year 3. Make field plantings with and without transgenic plants.

Year 4. Conduct research to place B. t. toxin-producing genes in selected areas of plant.

Year 5. Conduct field evaluations.

Colorado Potato Beetle Implementation Plan

Lead Array

1.3.1.1 Conduct foreign exploration for CPB natural enemies in temperate and high altitude South America.

Year 1. Planning and initial exploration.

Year 2. Continue exploration.

Year 3. Quarantine evaluation.

Year 4. Rearing and release.

Year 5. Monitoring, including genetic analysis of released populations.

1.3.1.2 Investigate potential of insect pathogens for control of CPB.

Year 1. Search for pathogens and bioassay for virulence.

Year 2. Continue per year 1.

Year 3. Introduce virulent pathogens into production.

Year 4. Field test virulent pathogens.

Year 5. Continue per year 4.

Safeguard Array

1.3.1.3 Investigate potential of predators and parasitoids for augmentation.

Year 1. Collect data on functional responses in the field.

Year 2. Develop mass rearing technology for most promising species.

Year 3. Perform field tests on most promising species.

Year 4. Develop delivery systems.

Year 5. Pilot test.

Supplemental Array

1.3.1.4 Investigate effectiveness of carabid populations for control of CPB.

Year 1. Develop carabid population monitoring procedures.

Year 2. Continue per year 1.

Year 3. Monitor field populations.

Year 4. Determine impact of carabid predation on CPB populations.

Year 5. Continue per year 4.

1.3.1.5 Evaluate the use of susceptible varieties as trap crops.

Year 1. Project planning and evaluation of germplasm.

Year 2. Continue per year 1.

Year 3. Small scale field tests.

Year 4. Continue per year 3, with fine-tuning.

Year 5. Pilot test.

1.3.1.6 Investigate means to avoid development of resistance in CPB populations to *B. t.* toxins produced by transgenic plants.

Year 1. Evaluate potential of CPB for development of resistance.

Year 2. Continue per year 1.

Year 3. Select additional *B. t.* toxin genes.

Year 4. Make field plantings with and without transgenic plants.

Year 5. Continue per year 4.

1.3.1.7 Develop a diapausing strain of *Edovum puttleri*.

Year 1. Fundamental studies of diapause mechanisms in Eulophidae.

Year 2. Continue per year 1.

Year 3. Continue per years 1 and 2.

Year 4. Introduce diapause genes into *E. puttleri* genome.

Year 5. Prepare environmental assessment.

Green Peach Aphid Implementation Plan

Lead Array

1.3.2.1 Investigate potential of introduced fungi, parasitoids, and predators for control of GPA.

Year 1. Overseas exploration.

Year 2. Testing on beneficial species.

Year 3. Continue per year 2; develop environmental assessment.

Year 4. Rearing and release.

Year 5. Recovery.

1.3.2.2 Develop potential of known fungi as biological insecticides on GPA.

Year 1. Select candidate fungi.

Year 2. Evaluate for efficacy in laboratory.

Year 3. Evaluate in small field plots.

Year 4. Evaluate in pilot study.

Year 5. Transfer technology.

1.3.2.3 Develop improved population monitoring systems and establish economic thresholds for control with regard to both density and vector potential.

Year 1. Evaluate available population monitoring technology.

Year 2. Select monitoring system and conduct small plot threshold tests.

Year 3. Field evaluate monitoring system and economic threshold.

Year 4. Continue per year 3.

Year 5. Use monitoring system in conjunction with economic threshold to determine timing of controls.

Safeguard Array

1.3.2.4 Develop potential of known pathogens, parasitoids, and predators for inoculation in early season alternate host plant systems.

Year 1. Select candidate beneficial agents.

Year 2. Establish production technology.

Year 3. Small plot evaluation.

Year 4. Continue per year 3.

Year 5. Field evaluation, including genetic analysis of released populations.

Optimizing Array

1.3.2.5 Evaluate interaction of GPA natural enemies with virus-resistant potato varieties.

Year 1. Select resistant varieties.

Year 2. Continue to select resistant varieties and determine candidate natural enemies.

Year 3. Cage test evaluations.

Year 4. Small plot evaluation.

Year 5. Large plot evaluation.

Supplemental Array

1.3.2.6 Evaluate use of chemical attractants, antifeedants, and repellents to manipulate GPA populations.

Year 1. Identify candidate compounds.

Year 2. Per year 1.

Year 3. Select best compounds.

Year 4. Field evaluation.

Year 5. Per year 4.

Mexican Bean Beetle Implementation Plan

Lead Array

3.3.1.1 Establish *Ooencyrtus sp.* in MBB-infested areas of the Northeastern States.

Year 1. Overseas exploration.

Year 2. Testing on beneficial species.

Year 3. Continue per year 2; develop environmental assessment.

Year 4. Rearing and release.

Year 5. Recovery.

Supplemental Array

3.3.1.2 Develop a diapausing strain of *Pediobius foveolatus*.

Year 1. Basic studies of diapause mechanisms in the genus.

Year 2. Continue per year 1.

Year 3. Attempt hybridizations and/or gene transfer.

Year 4. Continue per year 3.

Year 5. Rearing and release.

Plant Bugs Implementation Plan

Lead Array

4.3.1.1 Develop, evaluate, and integrate germplasm resistant to plant bugs with other biological methods of control.

Year 1. Identify other resistant factors in addition to nectariless cotton.

Year 2. Continue per year 1.

Year 3. Continue per years 1 and 2.

Year 4. Select resistant germplasm.

Year 5. Evaluate germplasm.

4.3.1.2 Manage plant bug populations in wild and other alternate host plant systems.

Year 1.Release and monitor known exotic parasitoids established in Northeast (*Peristenus spp.*) in the South. Evaluate effects of cultural control of early season hosts in small plots.

Year 2. Continue per year 1.

Year 3. Continue per years 1 and 2.

Year 4. Continue per years 1, 2 and 3.

Year 5. Evaluate augmentative release of promising candidates and if feasible, cultural control of large areas.

4.3.1.3 Improve monitoring and threshold evaluation systems (e.g. using semiochemicals and other techniques) to optimize control decisions.

Year 1. Isolate and identify pheromone; establish economic thresholds for plant bugs.

Year 2. Continue per year 1.

Year 3. Continue per years 1 and 2.

Year 4. Design and test pheromone traps.

Year 5. Evaluate pheromone traps in comparison with intensive sampling methods.

Citrus Rootweevil Complex

Lead Array

Establish research plots for evaluating the use of entomogenous nematodes for management of the CRWC with emphasis on citrus nurseries and areas with high risk for ground water contamination.

Year 1. Define conditions that are optimum for the application of entomogenous nematodes in citrus nurseries.

Year 2. Evaluate data and expand label to include citrus groves.

Year 3. Continue to evaluate field plots and commerical citrus treated with this biocontrol agent.

Year 4. Continue evaluation and expand research to include other agricultural crops.

Year 5. Compile and analyze data, including economic assessment.

Reduce CRWC populations in citrus with parasitoids.

Year 1. Select promising species.

Year 2. Continue to identify parasitoid species that are pathogenic for arthropod pests of citrus and ecologically adaptable to the citrus soil habitat, emphasis on soil adaptation.

Year 3. Develop formulations and application technologies and test performance on controlled environments.

Year 4. Evaluate control potential of selected species in field trials, emphasis on root protection and pest population reduction.

Year 5. Continue field evaluations and optimize performance.

Optimizing Array

Conduct foreign exploration for additional natural enemies.

Year 1. Identify natural enemies.

Year 2. Evaluate possible natural enemies.

Year 3. Facilitate production and release protocols.

Year 4. Conduct field cage studies.

Year 5. Conduct large field studie

Safeguard Array

Investigate potential of *Bearveria spp.* and other pathogens for control of citrus insects.

Year 1. Evaluate *Beauveria spp.* strains and other insect pathogens for virulence to immatures and adults.

Year 2. Evaluate interactions with physical synergists and antagonists in the citrus grove.

Year 3. Continue year 2 studies on the interactions between the host and pathogen under field conditions.

Year 4. Perform field tests with selected strains.

Year 5. Continue field testing and optimize performance.

Supplemental Array

Identify compounds that result in or are associated with resistance to arthropods.

Year 1. Identify existing resistant germplasm.

Year 2. Identify compounds associated with resistance.

Year 3. Incorporate resistance into a breeding program and develop new crosses.

Year 4. Evaluate resistance in field plots.

Year 5. Continue to identify compounds associated with resistance and the evaluation of plants in field plots.

Citrus Above Ground Arthropod Pests

Lead Array

Establish research plots for evaluating the use of parasitoids for management of the CAGAP with emphasis on arthropod pests that require the extensive use of chemicals (citrus rust mite).

Year 1. Define conditions that are optimum for the introduction of parasitoids.

Year 2. Select promising species.

Year 3. Continue to identify parasitoid species that are pathogenic for arthropod pests to citrus and ecologically adaptable to the citrus environment.

Year 4. Evaluate control potential of selected species in field trials.

Year 5. Continue field trials and optimize performance.

Optimizing Array

Conduct foreign exploration for additional natural enemies.

Year 1. Identify natural enemies.

Year 2. Evaluate possible natural enemies in quarantine.

Year 3. Facilitate production and contnue trials in quarantine.

Year 4. Conduct field cage studies.

Year 5. Conduct large field studies.

Safeguard Array

Investigate potential of fungi and other pathogens for the control of CAGAP.

Year 1. Evaluate fungi and other pathogens for virulence to immatures and adults.

Year 2. Evaluate interactions with physical synergists and antagonists in the citrus grove.

Year 3. Continue year 2 studies on the interactions between host and pathogen under field condition.

Year 4. Perform field tests with selected strains.

Year 5. Continue field testing and optimize performance.